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A. D. MELVIN, CHIEF OF BUREAU.

FEEDING FOR MEAT PRODUCTION.

BY

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
Washington, D. C., August 22, 1908.

Sir: I have the honor to transmit herewith, and to recommend for publication as a bulletin of this Bureau, a manuscript entitled "Feeding for Meat Production," by Dr. Henry Prentiss Armsby, who is in charge of the investigations in animal nutrition which have been in progress for some years at The Pennsylvania State College Agricultural Experiment Station by cooperation between that station and this Bureau. The paper consists of a general discussion of the principles underlying feeding for meat production, and while, as stated by Doctor Armsby, it does not include a report of any original work, it is believed that such a compilation may be useful in showing more clearly the practical bearings of the investigations mentioned.

Respectfully,

A. D. Melvin,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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FEEDING FOR MEAT PRODUCTION.

GENERAL PRINCIPLES.

DEFINITIONS.

By "meat" we understand in a general way the flesh of an animal as distinguished from the skeleton on the one hand, and the internal organs, hide, and other offal on the other hand. Meat in this general sense is separable mechanically into fat tissue and lean meat, both of these, but especially the latter, being of somewhat complex composition.

FAT TISSUE.

Description.—Fat tissue, or "adipose tissue," consists essentially of cells of connective tissue in which a large accumulation of fat has taken place, the protoplasm of the cells being reduced to a mere envelope surrounding the fat. These fat cells are held together by a basis of vascular connective tissue. Cells of this sort are found in almost all parts of the body, but there are two regions in which fat especially tends to accumulate and which constitute the great reserves of fat in the body, (1) the subcutaneous tissue, and (2) the connective tissue surrounding the internal organs, particularly the intestines and kidneys.

Composition.—Fat, of course, is the chief ingredient of adipose tissue, but the connective tissue and the remnants of protoplasm, which, together with adhering fat, yield the "cracklings" when the fat is melted out, make up an appreciable portion of its mass. Thus Henneberg, Kern, and Wattenberg[a] found the fat tissue from various parts of the fat sheep to contain from 85.33 to 90.35 per cent of fat. In later experiments with five lambs the same investigators[b] obtained the following average figures, to which the writer has added the energy content computed on the assumption that the fat-free dry matter consisted of protein:

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[a] Journal für Landwirtschaft, bd. 26, p. 381.

[b] Ibid., bd. 28, p. 289.

Composition of fat of lambs and computed energy value.

Constituent.	Subcutaneous fat.	Kidney fat.	Intestinal fat.
Water........per cent..	11.00	4.36	5.82
Fat........do....	84.49	93.89	92.15
Fat-free dry matter........do....	4.51	1.75	2.03
Total........do....	100.00	100.00	100.00
Computed energy value per kilogram........calories..	8,283	9,019	8,870

Beythien[a] reports the following extremes of composition of the fat tissue of commercial fresh beef, pork, and mutton:

Constituent.	Minimum.	Maximum.
	Per cent.	*Per cent.*
Water........	5.04	18.73
Fat........	76.10	93.02
Nitrogenous matter........	1.84	4.97
Ash........	.10	.23

LEAN MEAT.

Description.—The lean meat is still more complex in its make-up. Primarily it consists of muscular tissue. A muscle is briefly described by Foster[b] as consisting of "elementary muscular fibers, bound together in variously arranged bundles by connective tissue which carries blood vessels, nerves, and lymphatics." All these structural elements, speaking broadly, may be said to be protein in their general character, and the same is true of the connective tissue lying between the various muscles as well as of the tendons which form their attachments to the bones.

In addition to these proteid structures, however, muscular tissue contains more or less fat. Globules of this substance are found in the muscular fibers themselves, nor are there lacking indications that the complex protoplasm of the cell may contain fat in actual chemical combination with protein material. By far the larger part of the fat of the muscles, however, is to be found in the connective tissue in the form of the fat cells already described. In other words, larger or smaller masses of adipose tissue are formed between the muscles, the muscular bundles, or even between the single muscular fibers.

What we commonly speak of as lean meat, then, has a composition varying more or less according to the proportion of actual muscular fibers and of connective and vascular tissue, but especially with the extent to which fat deposition has taken place.

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[a] Biedermann's Central-Blatt für Agrikulturchemie und rationellen Landwirtschafts-Betrieb, bd. 30, p. 683.

[b] Text Book of Physiology, 1898, p. 82.

Composition.—Few analyses of the lean meat freed from adhering fat are on record, and its variations in composition may be considered more profitably in another connection. The following analyses by Jordan[a] of the meat from the entire carcasses of well-fed steers respectively 17 and 27 months old, the fat having been removed as fully as possible mechanically, may serve to indicate in a general way the composition of what might be called commercial lean meat. The figures are, in each case, the average for two animals, and the energy values have been computed by the present writer.

Average composition of lean meat of steers, and computed energy values.

Constituent.	In fresh meat.		In dry matter.	
	17 months old.	27 months old.	17 months old.	27 months old.
Water........per cent..	70.01	70.09	....	....
Ash........do....	.96	.95	3.19	3.18
Protein (by difference)........do....	19.83	19.30	66.15	64.53
Fat........do....	9.20	9.66	30.66	32.29
Total........do....	100.00	100.00	100.00	100.00
Computed energy value per kilogram........calories..	2,004	2,018	6,683	6,746

According to these figures, about two-thirds of the dry matter of lean beef consists of protein and somewhat less than one-third of fat.

PROPORTIONS OF FAT AND LEAN IN CARCASS.

The proportion of lean meat to fat tissue in the carcass is naturally quite variable, depending somewhat upon the age, but chiefly on the feeding of the animal, insufficient nutrition reducing the store of fat in the body to a minimum, while heavy feeding may cause the production of large amounts of it. Thus Lawes and Gilbert found the proportion of fat in the whole bodies of 10 farm animals to vary from 8.7 per cent in a well-fed ox to 42.3 per cent in a fat hog. Atwater[b] reports the following as the average composition of a side of beef of medium fatness:

Average composition of a side of beef of medium fatness.

	Per cent.
Water........	54.77
Protein........	17.20
Fat........	27.07
Ash........	.96
Total........	100.00

Lean cuts of meat, however, may contain much less fat than is indicated by the above statement. Thus Grindley and Emmett[c] analyzed seven samples of beef round from which the visible fat had been removed, the average of the seven analyses being as follows:

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[a] Maine Experiment Station, Report for 1895, Vol. II, pp. 36–77.

[b] U. S. Department of Agriculture, Office of Experiment Stations, Bulletin 21, p. 35.

[c] U. S. Department of Agriculture, Office of Experiment Stations, Bulletin 162.

Average composition of seven samples of beef round with visible fat removed.

Constituent.	Fresh substance.	Water-free substance.
	Per cent.	*Per cent.*
Water	73.30	....
Ash	1.13	4.27
Protein	18.79	70.67
Extractives	2.98	11.07
Fat	4.88	17.81

The minimum figure for fat was 3.19 per cent in the fresh substance, or 12.29 per cent of the dry matter.

Voit[a] found in the carefully prepared lean meat which he used as representing substantially protein food, and which had been most painstakingly freed from all visible fat, 0.91 per cent of ether extract in the fresh substance, equal to 3.77 per cent of the dry matter.

The term "meat" commonly suggests to the mind the muscular tissue of the animal, and has become almost synonymous with a proteid diet. It is evident, however, that the commercial growing of meat involves the production of considerably more fat than protein, and that in so far as this fat is actually consumed meat is far from being the distinctively protein food which it is ordinarily considered. Thus the so-called "nutritive ratio" of the above-mentioned side of beef, calculated in the usual manner, is about 1 to 3.5. On the other hand, however, it is equally true that the protein ingredients of meat are the distinctive ingredients for the sake of which meat is produced and eaten, while the fat, although a valuable nutrient, is to a certain extent subsidiary and accidental.

PROCESSES INVOLVED IN MEAT PRODUCTION.

Corresponding in a general way to the two main ingredients of meat—protein and fat—we may say that there are two physiological processes involved in its commercial production, namely, growth and fattening.

GROWTH.

The animal at birth is usually regarded as unfit to serve as human food. Moreover, even were this not the case, it would be in the highest degree uneconomic to fail to utilize the marked assimilative powers of the young animal in the production of body tissue (meat) from food. Consequently the production of meat involves more or less growth in all cases. This may, for special reasons, be concluded early, as in the production of lamb or veal, but as a whole the world's supply of meat is derived from animals at least approaching maturity. This growth of animals from birth to approximate maturity consists essentially of an increase in the proteid tissues.

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[a] Zeitschrift für Biologie, bd. 1, p. 95.

FATTENING.

The production of protein tissue during growth is normally accompanied by the production of more or less fat tissue, its amount depending largely on the nature and quantity of the feed. Experience has shown that the tenderness and palatability of the lean meat are notably greater when it is accompanied by considerable fat, and also that this improvement in quality may be effected by a comparatively short period of high feeding after growth has been substantially completed. It has become customary, therefore, to a large extent, to separate the business of meat production into two branches, conducted by different sets of individuals, one breeding animals and raising them until nearly mature and selling them to the other to be fattened.

It is obvious, however, that no sharp line can be drawn between the processes of growth and fattening. A calf or yearling may be fattened while growing, and a 2-year-old steer will continue to grow to some extent while being fattened. The two processes shade into each other, and economic considerations will decide whether they shall be carried on more or less simultaneously by a single producer or at different times by two different individuals.

LAWS OF GROWTH.

In any case it is clear that growth is the fundamental process in meat production, determining substantially the amount of meat in the narrower sense, while fattening affects chiefly its quality. We naturally take up first, then, a consideration of the laws of growth.

Growth may be defined briefly as consisting in an increase of the structural elements of the body, chiefly by cell multiplication, resulting in a gain in size and weight. Since these structural elements are mainly protein in character, this conception of growth makes it equivalent to an increase in the protein tissue of the body (including, of course, the mineral ingredients of the latter). In other words, any accompanying fat production, although in a sense involving growth of adipose tissue, may from this point of view be regarded as incidental. The actual processes of growth are substantially the same whether we produce fat lambs or veals or the lean and muscular colt or dairy calf.

RATE OF GROWTH.

Before proceeding to a discussion of the laws governing growth, it is important to consider the method of expressing the facts observed.

If we were to plat the successive weights or dimensions of a growing animal we should obtain what might be called the curves of weight or of stature. These rise rapidly at first and afterwards more slowly as the animal approaches maturity. Or we may plat in like manner the increments of weight or size observed in successive equal periods (day, week, month, or year), thus showing at what periods the absolute growth is most rapid.

It is evident, however, that an increase of a pound in weight by an animal weighing 500 pounds is relatively much less than the same increase in a 100-pound animal. A better expression of the processes of growth is afforded by a computation of the rate of growth, by which is meant the increment in a given unit of time expressed as a fraction of the amount at the beginning of that time. Thus in the instance just supposed the rate of growth in weight would be in the first case one five-hundredth and in the second one one-hundredth. In the second case the small animal is growing five times as fast as the larger, in proportion to its weight, and may be regarded as showing five times the energy of growth. An evident advantage of this manner of expressing the growth is that it permits of a comparison of animals of very different weights, as, for example, sheep with cattle.

INFLUENCE OF AGE ON RATE OF GROWTH.

Somewhat extensive observations, both on man and the lower animals, show that the average rate of growth as above defined diminishes from birth onward, the diminution being more rapid at first and slower as maturity is approached. This subject has recently been discussed in a most illuminating manner by Minot [a] on the basis of his own and others' observations on guinea pigs, rabbits, chicks, and other animals, as well as on man. Graphically the rate of growth is expressed by a descending curve, steep at first, but gradually becoming more and more nearly horizontal. Apparently, too, the same curve extends backward without material break into intrauterine life. Foster says: "It seems as if the impetus of growth given at impregnation gradually dies out." In the early stages of growth, therefore, the anabolic processes, which tend to build up tissue, predominate, while as time goes on the katabolic processes gain more and more over the anabolic until at maturity the two tend to become substantially balanced.

Moreover, as the following paragraphs will show, what is true of the rate of growth as measured by size or weight is also true of growth in the stricter sense as defined in the opening paragraph, i. e., the rate of increase of protein-tissue. Indeed, as we shall see later, the increase in weight of the young, growing animal is to a large extent synonymous with the growth of such tissue.

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[a] Popular Science Monthly, vol. 71 (1907), p. 193.

Percentage of feed protein retained in the body.—It has been shown that in the mature animal the katabolism of protein substantially keeps pace with its anabolism. Any considerable increase in the protein supply in the feed fails to cause a corresponding storage of protein in the body, but simply increases the amount broken down, resulting in a correspondingly increased excretion of nitrogenous metabolic products. Indeed, this is really implied in the conception of maturity. By a mature animal we mean one that has completed its growth, and growth consists essentially in the increase of the nitrogenous structural elements of the body. Obviously, therefore, if the capacity for growth has been exhausted, we should expect no material storage of protein, but that an excess of this material would serve chiefly or wholly as a source of energy to the organism.

With the young animal the case is different. Its rapidly growing cells and tissues demand a liberal supply of protein, and if this is afforded by the feed it will be largely utilized to build up tissue instead of undergoing nitrogen cleavage, and consequently a much larger percentage of the feed protein will be retained in the body. This difference between the protein metabolism in immature and mature animals is most readily shown by a comparison of the amount of feed protein with the amount stored in the body. Some of the more important data regarding domestic animals follow.

Soxhlet's well-known experiments on calves [a] afford interesting data on this point, which are summarized in the following table, the feed consisting of fresh whole milk:

Percentage of feed protein stored.

Animal.	Age.	Digested protein (N. ×6.25) of feed per day.	Daily gain of protein (N. ×6.25) by animal.	Digested protein stored.
	Days.	*Grams.*	*Grams.*	*Per cent.*
A	16–19	171.3	129.1	75.3
	30–33	228.4	163.6	71.6
B	15	330.8	231.8	70.1
	21	317.5	216.1	68.1
C	8	262.4	202.0	77.0

An investigation by Neumann [b] upon the influence of calcium phosphate and calcium carbonate on the metabolism of a calf somewhat older than Soxhlet's animals yielded the following figures for the daily nitrogen balance:

---

[a] Erster Bericht über Arbeiten der K. K. Landwirtschaftlich-Chemische Versuchsstation in Wien, 1870–77, pp. 101–155.

[b] Journal für Landwirtschaft, bd. 41, p. 343; bd. 42, p. 33.

Daily nitrogen balance.

Period.	Average age.	Feed.	Nitrogen digested.	Daily gain of nitrogen.	Digested nitrogen retained.
First series:	*Days.*		*Grams.*	*Grams.*	*Per cent.*
I	40	Skim milk	68.70	33.47	48.71
II	45	Skim milk+$Ca_3(PO_4)_2$	69.41	29.44	42.40
Second series:					
I	57	Skim milk	74.82	31.25	41.78
II	62	Skim milk+$CaCO_3$	73.86	23.12	31.30
III	69	Skim milk	77.60	27.88	35.92

Disregarding for our present purpose the relatively small effects produced by the calcium salts, it is evident that the results are in general accord with Soxhlet's, although the percentage stored is notably lower.

De Vries Jzn[a] conducted a series of digestion and metabolism experiments on calves at the Göttingen Experiment Station and obtained the following results for the protein metabolism:

Protein metabolism of calves.

Animal.	Period.	Average age.	Average live weight.	Feed per day.	Protein (N. × 6.25) per day.		
					Digested.	Stored in body.	
		Days.	*Kilos.*		*Grams.*	*Grams.*	*Per cent.*
A	I	50	82.39	14 kilograms skim milk	429.0	128.7	30.0
	II	65	94.96	7 kilograms skim milk 8 kilograms whole milk	425.3	170.4	40.1
	III	74	100.67	13.95 kilograms skim milk	428.3	117.6	27.5
	IV	100	119.94	14 kilograms skim milk 300 grams starch	398.1	148.9	37.4
B	I	38	82.00	14 kilograms skim milk	404.0	181.39	44.9
C	I	37	70.50	do	395.8	167.09	42.2
	II	64	88.60	do	[b] 386.9	111.56	28.8
D	I	45	69.29	9 kilograms whole milk	[b] 241.1	156.50	64.9
	II	63	81.38	9 kilograms whole milk+260 grams starch.	[b] 230.9	102.50	44.4
	III	74	85.71	9 kilograms whole milk	[b] 239.4	126.9	52.5

Wilson[c] fed three new-born pigs for sixteen days on skimmed cow's milk either alone or with addition of lactose and dextrose, respectively. The gains were determined by a comparison of the weight and composition of the animals with those of three other pigs of the same litter at the beginning of the experiment. Results of similar earlier experiments by Sanford and Lusk are also reported. For protein the results were as follows:

---

[a] Untersuchungen über die Fleischbildung des Saugkalbes. Inaugural Dissertation. Göttingen, 1896, p. 52.

[b] Digestibility estimated.

[c] The American Journal of Physiology, vol. 8, p. 197.

Storage of protein by new-born pigs.

Experimenter.	Feed.	Average age of animal.	Feed protein stored.
		Days.	*Per cent.*
Wilson	Skim milk	8	35.6
	Skim milk+lactose	8	44.5
	Skim milk+dextrose	8	42.1
Sanford and Lusk	Skim milk	7	23.0
	Skim milk+lactose	7	38.0
	Skim milk+dextrose	7	48.0

Investigations by Tschirwinsky[a] upon the sources of fat in pigs in which the gains of the animals were determined by means of comparative slaughter tests, gave the following results for the gain of protein between the ages shown:

Gain in protein by young pigs as shown by slaughter tests.

Animal.	Age.	Protein digested.	Protein gained.	Proportion of digested protein stored.
		Grams.	*Grams.*	*Per cent.*
No. 2	10 to 28 weeks	7,494	1,552	20.7
No. 3	9 to 22 weeks	3,554	1,193	33.6

Results of the same general character have been obtained in numerous experiments with infants, as for example those of Lange.[b]

Of experiments with somewhat older animals may be mentioned two with lambs by Henneberg, Kern, and Wattenberg and by Weiske, respectively.

The first of these investigations[c] had for its main object a study of the economy, from the point of view of meat production, of a fattening as compared with a growing ration for lambs. Two uniform lots of six lambs each were used. Lot 1 received a good growing ration for four periods, followed by a fattening ration in the fifth period, while lot 2 received a fattening ration from the start and was ready for the butcher at the end of the third period. Sample animals from each lot were slaughtered at the beginning and at intervals during the experiment and the carcasses partially analyzed. The results afford data for computing the gain of protein in the form of muscular tissue and the gain of total fat, but not, directly, the gain of total protein. Assuming the latter, however, to be 20.5 per cent of the fat-free body, the percentage of digestible protein retained in the body (not including the wool) was as follows:

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[a] Die Landwirtschaftlichen Versuchs-Stationen, bd. 29, p. 317.

[b] Atwater and Langworthy. Digest of Metabolism Experiments. U. S. Department of Agriculture, Office of Experiment Stations, Bulletin 45, pp. 30 and 326.

[c] Journal für Landwirtschaft, bd. 28, p. 289.

Gain in protein by lambs on growing and fattening rations for varying periods.

Lot.	Period.	Approximate average age.	Proportion of protein stored.
		Months.	*Per cent.*
1	I and II	9	7.73
	III and IV	21	4.06
	V	24	3.04
2	I and II	9	7.98
	III	15	2.54

Weiske's investigations[a] were upon two Southdown-Merino lambs about 4 months old, which were fed a good growing ration for about eleven months, this time being divided into nine periods of approximately equal length. After an interval of eight months a tenth period was added. In each period, usually during the last sixteen days, the balance of nitrogen, sulphur, and ash was determined. Owing to various irregularities and accidents, the conclusions are based chiefly upon the results on one animal (No. 2) except in Periods II and X.

The daily growth of wool is estimated to have contained 0.53 gram of nitrogen. Deducting this from the total gain observed gives the following results:

Nitrogen digested and retained by lambs on a growing ration.

Period.	Nitrogen per day and head.		
	Digested.	Retained in body.	
	Grams.	*Grams.*	*Per cent.*
I	12.04	2.17	18.02
II	13.05	2.05	15.71
III	12.94	1.62	12.52
IV	14.39	2.31	16.05
V	13.27	1.61	12.13
VI	12.92	1.53	11.84
VII	13.07	2.34	17.90
VIII	12.72	1.97	15.49
IX	11.98	0.39	3.26
X	11.18	1.59	14.22

Jordan's investigations[b] upon the relation of feed to the growth and composition of the bodies of steers afford data for comparing feed protein with protein gain in steers between the ages of 23 and 33 months. The gain of protein is computed from the weight and composition of the carcasses of similar animals at the two ages given, while the digestible protein of the feed is computed from the known[a] total protein on the assumption of average digestibility. Comparing No. 2 with No. 1 and No. 3 with No. 4, the average daily results, not including the protein of the hides, were as follows:

---

[a] Landwirtschaftliche Jahrbücher, bd. 9, p. 205.

[b] Maine Experiment Station, Report for 1895, vol. 2, pp. 36–77.

Comparison of average daily feed protein with protein gain.

Animal.	Protein digested.	Protein gained.	Digested protein stored.
	Pounds.	*Pounds.*	*Per cent.*
Steer No. 2	1.96	0.0971	4.97
Steer No. 3	1.05	.1123	10.72

Steer No. 2 had been fed for the preceding seventeen months on a ration considerably richer in digestible protein than that of steer No. 3.

Rate of gain of protein.—The foregoing results amply substantiate the introductory statement that in the very young animal a relatively large proportion of the feed protein may be retained in the body, and likewise show that this proportion diminishes rather rapidly as the animal grows older. The comparison, however, is likely to be disturbed by variations in the amount of protein fed. Since we may fairly suppose that the demand for protein at any given age is relatively fixed and independent of the supply, an excess of protein in the feed would obviously tend to reduce the percentage retained.

A more philosophical method of comparison is to compute the rate of gain of protein at different ages—that is, to compare the increment of protein during any given period with the amount contained in the body at the beginning of that period.

In those of the foregoing investigations in which control animals were analyzed at the beginning of the experiments we have an approximately correct measure of the original stock of protein in the bodies of the animals experimented on. Where no control animal was analyzed the attempt has been made to secure an approximate basis for computation by estimating the original stock of protein in the body from the live weight. For this purpose Lawes and Gilbert's figures for a fat calf have been used, but the percentage of fat has been reduced one-half, giving the following as the assumed composition:

	Per cent.
Water	69.54
Ash	5.17
Protein	17.76
Fat	7.53
Total	100.00

Having thus secured a starting point, it is easy to compute the stock of protein contained in the body at the end of each succeeding period, and likewise the average daily increment during each period expressed as a percentage of the amount present at the beginning of the period. Where there are intervals between the periods, the average rate of gain of each period has been assumed to continue until the beginning of the next. Arranging the results in the order of age, and without reference to species of animal, we have the results contained in the table which follows.

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[a] Or estimated in the case of the hay.

In the majority of these cases the initial protein content of the body was estimated from the live weight. It seems desirable also to compute the gain of protein per 1,000 pounds live weight. Except in the case of very fat animals, the results are likely to correspond substantially with those computed in the other way, while they have the advantage of being expressed in the manner usually adopted for expressing feeding requirements. This, of course, assumes that the protein requirement is proportional to weight, and not to surface, like the total feed requirement, an assumption which seems at least probable and which eliminates the element of varying size of animal.

Rate of gain of protein by animals of different ages.

Average age of animal.	Experimenter.	Animal.	Daily gain of protein.	
			Computed on total protein of body.	Computed per 1,000 pounds live weight.
Days.			*Per cent.*	*Pounds.*
7	Sanford and Lusk	Pig	7.269	5.621
8	Wilson	do	6.852	5.757
8	Soxhlet	Calf	2.347	3.994
15	do	do	2.076	3.552
18	do	do	1.644	2.803
21	do	do	1.722	3.024
32	do	do	1.693	2.755
37	De Vries Jzn	do	1.335	2.276
38	do	do	1.246	2.124
40	Neumann	do	1.795	2.945
45	do	do	1.449	2.419
45	De Vries Jzn	do	1.272	2.169
50	do	do	.880	1.500
50	Neumann	do	1.082	1.844
54	do	do	1.026	....
57	do	do	1.320	2.284
62	do	do	.939	1.611
63	De Vries Jzn	do	.678	1.209
64	do	do	.655	1.209
65	do	do	1.020	1.723
69	Neumann	do	1.062	1.823
74	De Vries Jzn	do	.713	1.271
100	do	do	.711	1.192
114	Tschirwinsky	Pig	.442	.663
134	do	do	.483	.740
140	Weiske	Lamb	.372	.651
177	do	do	.307	.499
214	do	do	.219	.360
254	do	do	.288	.449
290	Henneberg	do	.272	.303
293	Weiske	do	.179	.284
328	do	do	.160	.264
366	do	do	.232	.382
405	do	do	.178	.301
436	do	do	.033	.061
458	Henneberg	do	.068	.074
521	do	do	.087	.096
745	do	do	.067	.069
840	Jordan	Steer	.064	.089

It is perfectly obvious that the range of possible error in the single results obtained in this way is very considerable. Nevertheless the general teaching of the table is perfectly clear, viz, that the rate of growth of protein tissue, whether expressed per unit of body protein or per 1,000 pounds live weight, is relatively high in the newborn animal and decreases rapidly at first and more slowly later, tending to be asymptotic to the zero line. In other words, we obtain, as might have been anticipated, a curve quite similar to those expressing the rate of increase in weight or in stature.

If we let g equal gain of protein per day per 1,000 pounds live weight and a equal age in days, we find that a curve represented by the empirical equation[a]—

$$g = \frac{135}{a+20}$$

corresponds fairly well with the general average of the observed results. This is shown clearly by figure 1, in which the individual results recorded in the foregoing table are indicated by the dots, while the lower curve of the diagram is that represented by the above equation. Of course, considerable individual variations are to be expected, and no particular significance attaches to the mathematical form of the curve, but it would seem that we may tentatively use this formula as expressing in a broad general way the average protein growth at different ages.

Gain of protein by mature animals.—While it is true that the larger share of the feed protein supplied to a mature animal undergoes nitrogen cleavage, and that consequently the protein katabolism of such an animal is chiefly determined by the protein supply, the statement that the mature animal does not produce protein tissue needs modification.

In the first place, of course, the epidermal tissues (hair, wool, etc., hoofs, horns, and

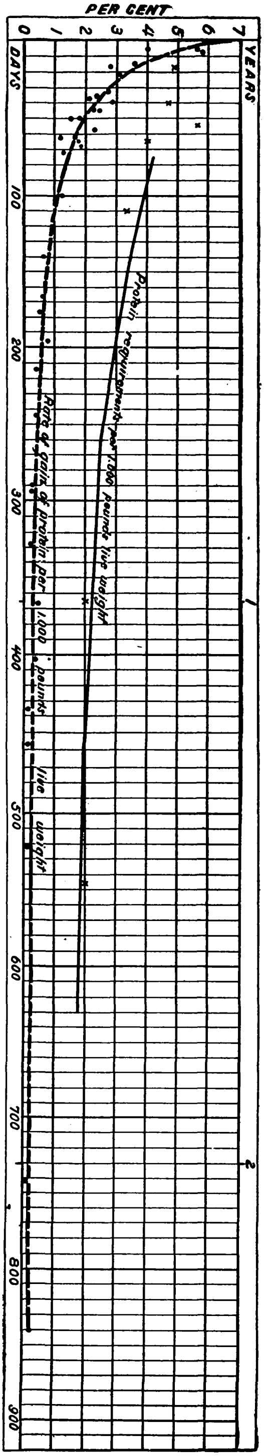

FIG. 1.—Diagram showing protein requirements and rate of gain of protein in growing animals.

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[a] The equation of a rectangular hyperbola.

epidermis proper) are continually growing and serve to store up a rather small amount of nitrogenous matter. Henneberg and Stohmann[a] estimate the nitrogen in the daily growth of hair in cattle at 1.5 to 4.5 grams, and Armsby and Fries[b] have obtained corresponding results. For sheep, quite varying figures have been obtained for the growth of wool. Some few data are also available on the growth of the feathers of geese.

In the second place, the deposition of large amounts of fat in the body would perhaps involve the growth of more or less connective tissue, and while the percentage of nitrogen in fat tissue is small, it is not impossible that it may sensibly affect the nitrogen balance. Thus if we assume adipose tissue to have the average composition shown on page 8, the formation *de novo* of 1 kilogram of such tissue would be equivalent to the storage of 4.6 grams of nitrogen. To what extent such a gain of fat represents a new growth of connective tissue and to what extent a storage of fat occurs in preexisting connective tissue there appear to be no data to decide.

Finally, it should be remembered that in many of the older metabolism experiments there is the probability of some loss of excretory nitrogen having occurred, either through incomplete collection of the excreta or especially by volatilization during the preparation for analysis. All these factors are relatively small, however, but there is another and much more important consideration. If we supply a mature animal with a diet deficient in protein or deprive it of food altogether, it is a familiar fact that it may live and continue to perform the essential bodily functions for some time, while losing daily a not inconsiderable amount of protein. To cite a single striking example, Rubner observed in a fasting rabbit up to the time of death, on the nineteenth day, a loss of 45.2 per cent of the computed nitrogen of the body.[c] While this is an extreme case, nevertheless it is evident that there must be a relatively large loss of body protein in those more moderate cases in which the deprivation of protein is not continued so long as to cause death. Furthermore, the losses occurring in these latter cases may be made good by subsequent feeding and the animal restored to its original state. Striking examples of the same fact are familiar in the human subject in the emaciation due to long illness and the restoration of the body during convalescence. Pugliere[d] has shown that a similar storage of protein takes place rather rapidly in the liver when a previously fasted animal receives feed again.

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[a] Neue Beiträge, etc., p. 446.

[b] U. S. Department of Agriculture, Bureau of Animal Industry, Bulletins 51 and 74.

[c] E. Voit. Zeitschrift für Biologie, bd. 41, p. 139.

[d] Jahresbericht über die Fortschritte der Tierchemie, bd. 34, p. 529.

In brief, it is evident that the protein content of the body of the mature animal may fluctuate within rather wide limits without necessarily causing any serious or permanent derangement of its functions. We can hardly regard such a fluctuation as consisting to any large extent of an actual destruction and rebuilding of the cells of muscular and other tissue. It seems more reasonable to suppose that it is effected chiefly by changes in the amount of cell contents—an alternate atrophy and hypertrophy of the cells under the influence of the changing protein supply. In other words, as regards its stock of protein, the organism may exist and function at a higher or lower level—a conclusion equivalent to Voit's conception of organized and circulatory protein in a slightly modified form. With carnivora on a largely protein diet, such as was used in Voit's experiments, the adjustment of the body to the protein supply seems to take place rather promptly. In the case of herbivora, however, the adjustment appears to be more gradual, possibly owing to the relatively large supply of nonnitrogenous ingredients in their food, and apparently some gain of protein may continue for a considerable time, although when expressed as a percentage of either the total feed protein, or especially of the body protein, the gain is relatively small.

The following table contains a summary of the principal results on record regarding the gain of protein by mature animals, omitting several negative results. The figures are exclusive of wool or feathers.

Gain of protein by mature animals.

Experimenter and publication.	Animal.	Age of animal.	Character of experiment.	Average live weight.	Gain of protein expressed as percentage of total body protein.	Daily gain of nitrogen[a] per head.	Daily gain of protein per head.	Daily gain of protein per 1,000 kilograms live weight.
				Kilograms.	*Per cent.*	*Grams.*	*Grams.*	*Kilograms.*
Henneberg, Fleischer, and Müller (Jahresbericht der Agriculturchemie, jahrg. 16-17, bd. 2, p. 145).	Sheep	4 years	Metabolism	34.2	0.038	0.32	1.92	0.056
					.123	1.04	6.24	.182
					.343	2.89	17.34	.507
Henneberg, Kern, and Wattenberg (Journal für Landwirtschaft, bd. 26, p. 549).	do	2¾ years	Slaughter	46.6	.089	5.53	33.18	.712
				50.0	.041	2.57	15.42	.308
Soxhlet (Biederman's Central-Blatt für Agrikulturchemie, etc., jahrg. 10, p. 674).	Swine	17½ months	do	119	.608	11.83	70.98	.596
				116	.291	5.49	32.94	.283
B. Schulze (Landwirtschaftliche Jahrbücher, jahrg. 11, p. 57).	Geese	9 to 10 months	do	3.68	.359	10.54	63.24	17.182
				3.84	.361	8.13	48.78	12.703
				3.83	.241	5.30	31.80	8.302
				3.83	.471	14.59	87.54	22.856
				3.81	.067	3.74	22.44	5.889
Meissl (Zeitschrift für Biologie, bd. 22, p. 63)	Swine	14 months	Metabolism	140	.176	6.08	36.48	.261
		15 months		70	.453	7.82	46.92	.670
		14 months		125	.177	5.46	32.76	.262
		18 months		104	.282	7.22	43.32	.416
Henneberg and Pfeiffer (Journal für Landwirtschaft, bd. 38, p. 215).	Sheep I	3½ years	do	44	.039	0.42	2.52	.057
					.299	3.25	19.50	.443
					.077	0.08	.16	.004
	Sheep II	3½ years	do	43	.193	2.03	12.18	.283
					.343	3.62	21.72	.505
					.096	1.01	6.06	.141
Pfeiffer and Kalb (Landwirtschaftliche Jahrbücher, jahrg. 21, p. 175).	Sheep I	(b)	do	42	.121	1.29	7.74	.184
		(b)			.067	0.71	4.26	.101
		(b)			.068	0.73	4.38	.104
	Sheep II	(b)	do	35	.134	1.15	6.90	.197
		(b)			.086	0.74	4.44	.127
		(b)			.141	1.21	7.26	.207
	Sheep III	(b)	do	42	.203	2.06	12.36	.294
	Sheep IV	(b)	do	35	.197	1.71	10.26	.292
		(b)			.027	0.23	1.38	.039

[a] Not including wool in case of sheep.

(b) Not stated.

The recent Moeckern investigations show even smaller gains of protein by mature fattening cattle in proportion to live weight. Grouping the large number of these experiments according to the amount of digestible protein fed, we obtain the following averages:

Gain of protein by mature cattle.

No. of experiments.	Average live weight.	Daily average digestible protein fed per head.	Daily average gain of nitrogen per head.	Daily gain of protein per 1,000 kilograms live weight.	Daily gain of protein in percentage of total body protein.[a]
	Kilograms.	*Grams.*	*Grams.*	*Kilograms.*	
7	656	343	9.53	0.087	0.0550
14	651	485	8.93	.082	.0518
18	667	713	14.57	.131	.0829
11	671	894	17.22	.154	.0974
10	691	1,497	18.08	.157	.0993

[a] Assumed to be 15.8 per cent of live weight.

Rate of growth of lean meat.—Most of the experiments just referred to relate to the growth of the total protein tissue of the body, including, besides the edible portion, the protein of the skin, hair, hoofs, horns, and other epidermal tissue, of the internal organs, and of the skeleton. While we may fairly assume that the increase of edible meat will be in a general way proportional to the increase of total protein, it is equally clear that there may be considerable departures from the average. It is important, therefore, to inquire into the rate of increase of the edible portion of the carcass. Unfortunately, however, the data upon this point are scanty, owing to the laborious and expensive nature of the experiments. About the only results available are those of Henneberg et al. on lambs and on mature sheep, and those of Jordan on steers—that is, these are the only ones which permit of a comparison of the rate of growth of similar animals in successive periods.

Henneberg's experiments on lambs[a] have been outlined on a previous page. The following table shows the gains of fat-free lean meat in the same experiments, as compared with the gains of total protein, the latter being computed from the increase of the "fat-free body" by multiplication by 0.205. The meat refers only to the meat of the "butcher's pieces," freed from sinews and coarser connective tissue by passage through a meat grinder.

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[a] Journal für Landwirtschaft, bd. 28, p. 289.

Gain of fat-free lean meat and total protein by lambs.

Lot.	Period.	Length of period.	Character of ration.	Average age of animals.	Gain per week and head	
					Fresh, fat-free meat.	Total dry protein (estimated).
		Days.		*Days.*	*Kilograms.*	*Kilograms*
1	I and II	203	Growing	290	0.114	0.056
	III and IV	259	.....do	521	.053	.031
	V	175	Fattening	745	.042	.029
2	I and II	189	.....do	290	.130	.077
	III	147	.....do	458	.040	.026

In this case the gain of fat-free lean meat was, in general, parallel to the gain of total protein (or more strictly to the gain of the fat-free body), diminishing with advancing maturity. Apparently, however, the rate of gain of total protein increased slightly as compared with that of edible meat, as shown by the following table of the relative gains in the several periods, that on Periods I and II being taken as unity:

Relative gains of fat-free lean meat and total protein by lambs.

Lot.	Period.	Fat-free lean meat.	Total protein.
		Kilograms.	*Kilograms.*
1	I and II	1.000	1.000
	III and IV	.465	.554
	V	.368	.518
2	I and II	1.000	1.000
	III	.308	.338

The experiments with mature sheep[a] were conducted upon substantially the same plan as those with lambs, with the following results:

Gain of fat-free meat and total protein by mature sheep.

No. of animal.	Condition at close of period.	Length of period.	Gain per week and head.		
			Fresh, fat-free meat.	Dry, fat-free meat.	Total dry protein (estimated).
			Kilograms.	*Grams.*	*Kilograms.*
6	Fat	70 days	−0.015	1.99	+0.039
8	Very fat	203 days	− .008	3.99	+ .018
8	.....do	Last 133 days	+ .020	5.04	+ .007

In no case was there any material gain in the weight of fresh, fat-free meat, and while there was a slight gain of dry matter in the fat-free meat, it was, in the earlier stages of fattening, much less than the computed gain of total protein. The greater increase during the later stages of the experiment was due chiefly to an increase in the nitrogenous extractives of the meat, particularly of the soluble protein, rather than of its insoluble protein, about two-thirds of the small computed gain of protein being in the form first named.

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[a] Journal für Landwirtschaft, bd. 26, p. 549.

Jordan's experiments include a comparison of the weights and chemical composition of two pairs of animals at the end of twenty-seven months' and seventeen months' feeding, respectively. The protein of the lean meat, after mechanical separation from the fat tissue, and the total body protein were as follows:

Gain of protein of lean meat and of total protein by steers.

No. of animal.	Average age.	Protein of lean meat.	Total protein of body.
		Pounds.	*Pounds.*
2	32 months	42.13	167.94
1	22 months	[a] 37.96	136.30
	Gain in 10 months	4.17	31.64
	Gain per day	.0128	.0971
3	32 months	43.24	161.38
4	22 months	[a] 35.08	126.30
	Gain in 10 months	8.16	35.08
	Gain per day	.0261	.1123

[a] Nos. 1 and 4 were somewhat lighter animals than Nos. 2 and 3. The protein content has been computed to the live weight of the heavier animal in each case.

It would appear, so far as conclusions can be safely drawn from these few results, that while the gain of lean meat, like that of total protein, diminishes with age, the diminution is more rapid in the former case than in the latter. At all ages the storage of total protein (or, more exactly, the increase in the fat-free body) considerably exceeds the gain of lean meat proper, and with increasing maturity this difference seems to become relatively greater.

INFLUENCE OF PROTEIN SUPPLY ON RATE OF GROWTH.

The essential feature of growth being the increase in protein tissue, the question is at once suggested whether the rate of growth may be stimulated or the reverse by an abundant or limited protein supply in the feed.

As regards the latter branch of the question, it is self-evident that if the feed contains less digestible protein than corresponds to the normal rate of growth, the latter must be diminished by simple lack of material. A considerable number of feeding experiments have been made with growing animals, notably with swine, in which the character of the carcasses produced on rations poor and rich in protein (the so-called "feeding for fat and for lean") has been compared. In few or none of these experiments has the actual increase of proteid tissue been determined, but in a majority of them there has appeared to the eye a deficiency in the development of the muscular system on the protein-poor rations, accompanied usually by a relative excess of fat. The results of Fuller[a] upon young pigs appear to show in a very striking manner the effect of a deficient protein supply in limiting growth, but the presence of intestinal worms in large numbers in the corn-fed lot detracts from the force of the conclusions. Moreover, there are not lacking indications that in some of the other experiments the deficiency of lean meat and excess of fat were more apparent than real, and that the distribution of the fat in the carcasses rather than its amount was the controlling factor in their commercial valuation.

When we ask, however, whether the rate of growth can be stimulated by an abundant protein supply, the answer is not so easy. Evidently we can not readily compare results on the same animal at different ages on account of the marked influence of the latter factor on the rate of gain, while comparisons between two animals or lots are liable to be disturbed by the factor of individuality. Moreover, aside from these difficulties, there is no obvious way of determining what is to be regarded as a normal rate of growth or whether the protein supply of the check animal or lot has been sufficient to enable it to reach this normal rate. A review of such of the experiments cited in connection with the discussion of the influence of age on protein metabolism as afford data bearing on this point seems to indicate that there may be some stimulative effect of this sort. In most cases the greater absolute and relative gain of protein is found in those animals receiving the greater amount of protein in their feed. The most marked instances are Soxhlet's results with calves, Henneberg's with lambs, and Jordan's with steers. In all these cases the more liberal protein supply seems to have hastened growth in the earlier periods, while in the later periods the growth was less than on the lower protein supply. This is true also of the averages of the Moeckern experiments on mature animals, cited on a previous page.

The effect, however, was in nearly all cases relatively small. The fact, pointed out in the same discussion, that an abundant protein supply may, for a time at least, cause more or less storage of protein in mature animals points in the same direction. Such storage was there interpreted as probably consisting chiefly in a hypertrophy of the cells. There seems no obvious reason why the same effect may not be produced in growing animals, and it is easy to imagine that a surplus of protein in the contents of the cell may tend to stimulate the growth of the bioplasm itself.

Abderhalden[b] has shown that the rate of growth of different species of animals is quite closely parallel to the percentage of protein in the milk, but, as Minot[c] points out, this is in all probability the result of an adaptation of the composition of the milk to the demands of the young animal, the rate of growth being cause and not consequence.

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[a] Wisconsin Experiment Station, Report 21 (1903–4), p. 25.

[b] Zeitschrift Physiologische Chemie, bd. 26, p. 497.

[c] Loc. cit.

It would seem, then, that we may regard each animal as endowed with a certain normal rate of growth. A liberal supply of protein may perhaps stimulate this rate of growth somewhat, resulting, for a time at least, in a greater storage of protein, and perhaps a tendency to earlier maturity, although it seems unlikely that the effect can be great. On the other hand, it appears reasonably certain that the rate of growth may be materially reduced by a deficiency of protein in the ration, even when this deficiency is not so great as to result in any obvious disturbance of the bodily functions or even a greatly diminished gain in live weight.

PROTEIN REQUIREMENTS.

In the foregoing paragraphs have been outlined the general features of the production of protein tissues in the growing animal. We next inquire what quantities of protein are required in the feed to insure the "normal" rate of growth.

Requirements for growth.—Obviously, the feed must contain at least an amount of protein equal to that stored as growth. This amount per 1,000 pounds live weight can, as we have seen, be roughly and approximately expressed by the equation

$$g = \frac{135}{a + 20}.$$

While the rate of growth doubtless shows considerable variation in different individuals, the diagram already presented seems to justify us in regarding the figures thus obtained as representing fairly well the "normal" rate of growth, for which proteid material must be provided.

Requirements for maintenance.—In addition to the protein required for growth, the feed must supply sufficient protein to make good the katabolism of this material which is constantly going on in living tissue; that is, it must contain the minimum of protein required for maintenance. For mature cattle this appears to be from 0.4 to 0.6 pound per day per 1,000 pounds live weight, or perhaps 0.5 pound as a general average. For mature sheep the current feeding standards call for 1.2 to 1.4 pounds per 1,000 pounds live weight, but there is little doubt that, like the current standard for cattle, this is too high. The average growth of wool per day would scarcely amount to more than 0.15 pound of protein per 1,000 pounds live weight, and even if we assume the protein metabolism of sheep to be more active than that of cattle it would seem that 0.75 to 0.80 pound per day would be an ample allowance for maintenance. For swine no data seem to be available.

The above statements refer to the maintenance requirements of mature animals. Whether the same figures apply substantially to growing animals, or whether their necessary protein metabolism, like their total metabolism, is more active, relatively to their weight, is largely a matter of conjecture. Assuming, for the time being, that the former is the case, and letting m equal the daily protein requirement for maintenance and p equal total protein requirement, the formula above becomes

$$p = \frac{135}{a + 20} + m.$$

Is protein required for other purposes?—If we computed the average protein requirements at different ages by means of the foregoing formula, letting m equal 0.50, we obtain results differing most strikingly from accepted figures, as the following comparison of the computed results with the Wolff-Lehmann and with Kellner's standards for beef cattle makes evident.

Protein requirement of cattle per 1,000 pounds live weight.

Age.	Computed from formula.	Wolff-Lehmann standards.	Kellner's standards.	
			Milking and working animals.	Fattening animals.
Months.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
2 to 3	1.92	4.3	3.4	4.5
3 to 6	1.37	3.5	2.8	3.5
6 to 12 ...	.97	2.5	2.3	2.8
12 to 18 ..	.79	2.0	1.8	2.2
18 to 24 ..	.71	1.8	1.3	1.5

The foregoing comparison, however, simply shows that the computed amounts of protein are only about one-half those thought to be advisable in practice, without in itself affording any proof that the latter estimates are too high. As a matter of fact, while more recent investigation has shown that the Wolff-Lehmann standards for protein are unnecessarily high for mature or nearly mature animals, the same thing does not seem to be true of the standards for growth, as appears from the comparisons summarized on page 71.

It is quite conceivable and indeed probable that the growing body has other demands for protein than those just indicated. Thus, there may very well be a considerable necessary margin of waste in the conversion of feed protein into body protein. So, too, the digestion of the relatively large amount of feed constituting a growing or fattening ration, as compared with a maintenance ration, would apparently call for a larger production of digestive enzymes, which are doubtless protein in nature. The extent of this demand, however, and the degree to which the secreted enzymes are reabsorbed are largely matters of speculation. It seems possible that part of the "depression" of digestion with rations poor in protein may arise from deficient digestive ferments. At any rate, the inferior digestibility of such rations is a factor in the practical economy of feeding.

Finally, the processes both of growth proper and of fattening involve a large amount of metabolic activity in the body. But a relatively small portion of the metabolizable energy of the feed is finally stored up in the body, the larger share of the matter bearing it being katabolized, and its energy finally liberated as heat. It seems quite in accord with what we know of the katabolic activity of the cells and tissues of the body to suppose that this increased activity on their part may involve an increased breaking down of their protein as well as of their nonnitrogenous constituents, and so give rise to a corresponding demand for protein in the feed.

Unfortunately, few or no experiments directed specifically to the determination of the necessary minimum of protein for animals of different species and of different ages are on record, so that for practical purposes we are compelled to glean such information as we can on this point from practical feeding experiments in which the protein supply has varied. These data will be considered later in another connection.

INDIVIDUAL DIFFERENCES.

It is a matter of common experience that there exist marked differences between individuals of the same species both as to the weight finally attained by the mature animal and as to the rate of growth at the same age.

We should naturally be inclined to interpret this fact as indicating corresponding individual differences in the rate of gain of proteid tissue, but the writer is not aware of any recorded experiments bearing specifically on this point. It is true that the quality of early maturity is popularly attributed to the meat breeds, but as regards cattle at least Henry[a] has shown that the data at hand fail to prove that the beef breeds as such show a greater rate of gain in live weight or a greater weight at maturity than do the dairy breeds. If we are correct in ascribing the individual differences noted above to variations in the rate of growth of protein tissue, it would seem to open up a field for investigation of the highest interest to the breeder and feeder.

LAWS OF FATTENING.

As already pointed out, fattening is, strictly speaking, as the word implies, the accumulation of adipose tissue in the body, resulting in or at least accompanied by an improvement in the quality of the lean meat. Such a gain of fat by the animal of course implies an excess of feed over the requirements for maintenance and for normal growth of protein tissue, and, conversely, any period of heavy feeding will cause a fattening whether the animal be young or mature.

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[a] Feeds and Feeding, second edition, p. 374.

For our present purpose it will be convenient to use the term fattening more nearly in its commercial sense as denoting heavy feeding, whether of mature or immature animals, for the production of marketable carcasses..

COMPOSITION OF INCREASE.

The amount of protein gained, as has been shown, is largely dependent upon the age and to a less degree upon the individuality of the animal, although probably affected to some extent by the supply of feed protein. The fat formation, on the other hand, is primarily dependent, in a broad general way at least, upon the total feed supply. Accordingly, we should anticipate that the composition of the increase would vary with the age of the animal, consisting more and more largely of fat with increasing maturity.

Proportion of protein and fat.—From this point of view the nature of the increase is best characterized by the ratio of protein to fat—that is, by the composition of the water-free and ash-free gain, leaving for later consideration the actual composition of the total gain in live weight. It seems desirable also to distinguish, so far as possible, between the gain of protein in the form of lean meat or of the soft tissues and that in the form of epidermal tissues (hair, feathers, hoofs, horns, etc.), although as a matter of fact the proportion in the latter is relatively slight except in a few experiments with geese.

The following tabulation contains the results of the experiments accessible to the writer which afford more or less complete data as to the composition of the increase. Those on growing animals are arranged roughly according to age.

Proportion of protein and fat in the gains made by growing and mature animals.

GROWING ANIMALS.

Author.	Nature of experiments.	Designation of animal or period.	Average age.	Composition of dry and ash-free increase.		
				Protein of epidermis.	Remainder of protein.	Fat.
				Per cent.		*P. ct.*
Wilson	Comparative slaughter tests on pigs.	Skim milk	8 days	92.50		7.50
		Lactose	8 days	91.08		8.92
		Dextrose	8 days	91.35		8.65
Soxhlet	Respiration experiments on calves.	B 1	15 days	54.57		45.43
		B 2	21 days	49.90		50.10
		C	8 days	56.42		43.58
Tschirwinsky	Comparative slaughter tests on pigs.	No. 3	114 days	0.10	18.19	81.71
		No. 2	134 days	.16	15.16	84.68
Henneberg, Kern, and Wattenberg.	Comparative slaughter tests on lambs.	Lot 1:				
		Periods I and II	290 days		[a]21.21	78.79
		Periods III and IV.	521 days		[a]9.31	90.69
		Period V	745 days		[a]7.34	92.66
		Lot 2:				
		Periods I and II	290 days		[a]16.08	83.92
		Period III	458 days		[a]6.40	93.60
Jordan	Comparative slaughter test on cattle.	Average	840 days		25.06	74.94

Proportion of protein and fat in the gains made by growing and mature animals—Cont'd.

MATURE ANIMALS.

Author.	Nature of experiments.	Designation of animal or period.	Average age.	Composition of dry and ash-free increase.		
				Protein of epidermis.	Remainder of protein.	Fat.
				Per cent.		*P. ct.*
Henneberg, Fleischer, and Müller.	Respiration experiments on sheep.	Period I	4 years	....	4.26	95.74
Henneberg, Kern, and Wattenberg.	Comparative slaughter tests on sheep.	No. 6	2¾ years	....	3.84	96.16
		No. 8, total		....	3.71	96.29
		No. 8, last period		....	3.26	96.74
Soxhlet	Comparative slaughter tests on swine.	No. 1	16½ months	35.48		64.52
		No. 2		11.26		88.74
B. Schulze	Comparative slaughter tests on geese.	No. 1	9 months	1.69	10.99	87.32
		No. 2		7.53	−1.94	109.47
		No. 3		−.07	8.57	91.50
		No. 4		−1.46	6.33	95.13
		No. 5		−4.71	9.41	85.88
		No. 6		1.89	2.58	95.53
Chaniewski	do	No. 2	(?)	8.39	1.05	90.56
		No. 3	(?)	6.44	−5.30	98.86
Meissl et al.	Respiration experiments on swine.	No. 1	14 months	9.75		90.25
		No. 2	15 months	10.67		89.33
		No. 3	14 months	16.39		83.61
		No. 4	18 months	15.16		84.84
Lawes and Gilbert.	Comparative slaughter tests.	Average for cattle, sheep, and swine.	....	9.67		90.33

[a] Computed from "fat-free body."

In addition to the above, Kühn's and Kellner's extensive investigations at the Moeckern Experiment Station call for special consideration. These were respiration experiments on mature cattle, the actual experimental periods ranging from two to four weeks, but not usually less than three, the periods not infrequently being separated by transition feedings of two or three weeks.

Out of all the experiments, 60 in number, which show a gain of both protein and fat, only 3 show less than 70 per cent fat in the total gain and only 3 a percentage above 95. Rejecting these 6 and grouping the remainder according to the percentage of fat, we have the following results:

Results of respiration experiments with mature cattle at the Moeckern Experiment Station.

Group No.	Number of experiments.	Digestible protein fed.	Range of percentage of fat in gain.	Composition of dry ash-free gain.		Average total energy of gain.	Metabolizable energy of feed.
				Total protein.	Fat.		
		Grams.		*Per cent.*	*Per cent.*	*Calories.*	*Calories.*
I	5	822	70—74.99	26.25	73.75	3,858	21,519
II	7	829	75—79.99	23.30	76.70	3,771	21,210
III	19	598	80—84.99	17.17	82.83	4,445	21,762
IV	14	1,064	85—89.99	12.55	87.45	6,288	26,483
V	9	644	90—94.99	8.06	91.94	6,185	25,783

The actual gains of protein and fat per day and head were as follows:

Actual gain of protein and fat per day and head.

Group No.	Protein.	Fat.
	Grams.	*Grams.*
I	119.1	334.8
II	90.0	296.3
III	81.6	393.3
IV	87.5	609.5
V	53.3	608.0

It is evident from the foregoing tables that the gain of organic matter by the fattening animal consists chiefly of fat except in the case of the very young animal. In but few cases does the percentage of fat in the organic matter gained fall below 80, and in the majority of cases it ranges between 80 and 90.

Composition of total increase.—From such of the foregoing experiments as admit of it, the composition of the total increase in live weight has been computed, with the following results:

Composition of total increase in live weight in growing and mature animals.

GROWING ANIMALS.

Author.	Designation of animal or period.	Average age.	Composition of increase.				Energy of 1 kilogram of increase.
			Water.	Ash.	Protein.	Fat.	
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Calories.*
Wilson	Skim milk	8 days	80.08	[a] 0.03	18.40	1.49	1,191
	Lactose	8 days	78.91	[a] 1.42	17.92	1.75	1,188
	Dextrose	8 days	79.44	[a] 1.62	17.30	1.64	1,142
Soxhlet	B. 1	15 days	61.28	3.63	19.15	15.94	2,606
	B. 2	21 days	62.13	3.50	17.15	17.22	2,614
	C.	8 days	62.55	3.35	19.24	14.86	2,508
Tschirwinsky	No. 3	114 days	46.51	3.73	9.10	40.66	4,382
	No. 2	134 days	34.23	2.24	9.73	53.80	5,666
Henneberg, Kern, and Wattenberg.	Lot I:						
	Periods I and II	290 days	43.84		[b] 11.31	44.85	4,906
	Periods III and IV	521 days	27.27		[b] 7.03	65.70	6,643
	Period V	745 days	22.18		[b] 5.72	72.10	7,175
	Lot II:						
	Periods I and II	290 days	38.41		[b] 9.91	51.68	5,475
	Period III	458 days	16.03		[b] 4.13	79.84	7,820
Jordan [c]	Average	840 days	39.65	6.18	13.57	40.60	4,630

MATURE ANIMALS.

Author.	Designation of animal or period.	Average age.	Water.	Ash.	Protein.	Fat.	Energy of 1 kilogram of increase.
Henneberg, Kern, and Wattenberg.	No. 6	2¾ years	13.00		[b] 3.35	83.65	8,138
	No. 8 (total)		12.48		[b] 3.23	84.27	8,190
	No. 8 (last period)		11.23		[b] 2.90	85.87	8,323
Soxhlet	No. 1	16½ months	58.96	3.17	13.42	24.45	3,088
	No. 2	16½ months	35.99	3.62	6.80	53.59	5,479
B. Schulze	No. 1	9 months	46.53	1.01	6.65	45.81	4,731
	No. 2		35.00	2.15	−5.96	68.81	6,197
	No. 3		33.12	1.46	5.56	59.86	6,004
	No. 4		23.79	1.62	3.63	70.96	6,249
	No. 5		47.28	0.69	7.35	44.68	4,664
	No. 6		36.65	0.30	2.82	60.23	5.883
Chaniewski	No. 2	(?)	42.92	2.21	5.20	49.67	5.015
	No. 3	(?)	25.37	0.54	0.84	73.25	7,007
Lawes and Gilbert	Average for cattle, sheep, and swine.		23.80	1.10	7.26	67.80	7,055

[a] By difference.

[b] Computed from "fat-free body."

[c] The figures differ slightly from those computed by the author.

The most obvious showing of this, as of the previous tabulations, is the wide range in the composition of the increase. Even aside from the very young animals, in which the gain consists chiefly of water and protein, we see that the percentage of dry matter in the gain and the proportions of fat, protein, and ash in the latter vary within wide limits. It is very clear that a pound of gain in weight may require a very different food expenditure for its production in different cases, and is an exceedingly variable standard by which to measure the effects of a ration.

Influence of progressive fattening.—The results just cited, in most cases, are either those of an entire fattening period, or else, especially in the case of the respiration experiments (including the Moeckern experiments), those of a short period of feeding with at most only moderately fat animals.

It would appear probable that with the progress of the fattening the proportion of protein stored would tend to decrease, and that the gain would consist to an increasing extent of fat. This supposition is confirmed by the results of Henneberg et al. on lambs and sheep (included in the foregoing tables), but these appear to be the only data bearing on this point. Their results on lambs show a marked diminution in the percentage of water in the gain, a result which corresponds to the general showing of the last table and with the well-known fact that the bodies of young animals contain a higher percentage of water than do those of mature animals. The proportion of protein in the dry matter of the gain decreases notably, while that of fat, of course, increases correspondingly. In the mature sheep there is also a falling off in the percentage of water and protein and an increase in that of fat, in the later stages of fattening, but the differences are relatively small and perhaps within the limits of error of such experiments.

Energy value of increase.—The wide range of composition shown by the gain in live weight has already been commented upon. It is of some interest, however, to reduce these results to a common measure by computing the energy value of the increase. Estimating 5.7 calories per gram of protein and 9.5 calories per gram of fat, the computed energy values per kilogram of gain are as shown in the last column of the preceding table.

INFLUENCE OF FATTENING ON COMPOSITION OF LEAN MEAT.

As has been already pointed out, the accumulation of adipose tissue in the fattening process appears to be of secondary importance, the main object being to improve the quality of the lean meat. It becomes of interest, therefore, to inquire what chemical or other differences exist between the meat of lean and of fat animals. Comparatively few data are available upon this point, but, nevertheless, some interesting indications may be found.

In Henneberg's experiments on sheep,[a] the meat, after trimming off as much fat as practicable, was ground, the coarser connective tissue being removed in the process. This "meat" contained in the water-free substance:

Relative proportion of fat and fat-free meat in the lean meat of sheep.

	Sheep No. 18 (lean).	Sheep No. 6 (fat).	Sheep No. 8 (very fat).
	Per cent.	*Per cent.*	*Per cent.*
Fat	24.87	15.04	16.27
Fat-free meat	75.13	84.96	83.73
Total	100.00	100.00	100.00

The meat of sheep No. 18 was not trimmed and there is no guaranty of uniformity of trimming in the other two cases.

The composition of the fresh fat-free meat of sheep No. 8 and No. 18 was as follows:

Composition of fresh fat-free meat of sheep.

	Sheep No. 18 (lean).	Sheep No. 8 (very fat)
	Per cent.	*Per cent.*
Water	79.41	79.02
Insoluble protein	15.85	15.73
Extractives:		
Protein	1.29	1.93
Nonprotein	2.18	2.17
Ash	1.27	1.15
	4.74	5.25
Total	100.00	100.00

There was evidently an increase in the extractives of the fat-free meat and a corresponding decrease in the percentage of water, while the proportion of insoluble protein (muscular fiber) is practically unchanged. Comparing the absolute amounts contained in the bodies of the two animals, the computed gain during fattening was—

		Grams.
Insoluble protein		38.7
Extractives:		
Protein	82.0	77.0
Nonprotein	4.2	
Ash	−9.2	
Total		115.7

Henneberg's experiments on lambs,[b] computed in the same manner as those upon sheep, give the following as the composition of the trimmed butcher's cuts:

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[a] Journal für Landwirtschaft, bd. 26, pp. 585–611.

[b] Ibid., bd. 28, pp. 359–377.

Relative proportion of fat and fat-free meat in the lean meat of lambs.

	Fat-free meat, fresh.	Fat.
Lot 1:	*Per cent.*	*Per cent.*
Beginning of Period I	88.16	11.84
End of Period II	87.38	12.62
End of Period IV	80.24	19.76
End of Period V	81.28	18.72
Lot 2:		
End of Period II	84.72	15.28
End of Period III	75.53	24.47

If we may assume that the trimming of the meat was uniform, there is shown clearly an increase in the fat content of the meat, both during growth and during the fattening of lot 2, but the fattening period (V) for lot 1 shows no increase over the preceding period.

The composition of the fat-free meat was as follows:

Composition of fat-free meat of lambs.

	Lot 1.				Lot 2.	
	Beginning of Period I.	End of Period II.	End of Period IV.	End of Period V.	End of Period II.	End of Period III.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Insoluble protein	14.89	15.12	15.74	15.90	14.86	15.65
Soluble protein	1.56	1.72	1.63	1.90	2.16	2.16
Nonprotein	1.44	1.74	2.14	2.40	1.66	1.84
Ash	1.10	1.07	1.14	1.20	1.11	1.18
Total dry matter	18.99	19.65	20.65	21.40	19.79	20.83
Water	81.01	80.35	79.35	78.60	80.21	79.17
	100.00	100.00	100.00	100.00	100.00	100.00
Total extractives	4.10	4.53	4.91	5.50	4.93	5.18

There is evident in both lots an increase in the percentage of dry matter in the fat-free meat, but there seems to be no marked difference in this respect between the effects of the growing rations of lot 1 in the first four periods and those of the fattening ration of lot 2 and of lot 1 in Period V. The increase in the percentage of extractives was relatively greater than in that of the insoluble protein, as the following computation of the composition of the dry matter shows:

Composition of dry matter of fat-free meat of lambs.

In fat-free dry matter.	Lot 1.				Lot 2.	
	Beginning of Period I.	End of Period II.	End of Period IV.	End of Period V.	End of Period II.	End of Period III.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Insoluble protein	78.42	76.95	76.23	74.30	75.10	75.13
Soluble protein	8.21	8.75	7.89	8.88	10.90	10.37
Nonprotein	7.58	8.85	10.36	11.21	8.39	8.83
Ash	5.79	5.45	5.52	5.61	5.61	5.67
	100.00	100.00	100.00	100.00	100.00	100.00
Extractives	21.58	23.05	23.77	25.70	24.90	24.87

The fattening appears to have caused some increase in the total extractives as compared with the growing rations. The difference is due to a somewhat marked increase in the soluble protein in lot 2, while the nonprotein shows a relative decrease. The final fattening of lot 1 also caused an increase in the extractives rather than in the insoluble protein, this increase, however, being chiefly in the nonprotein.

In Jordan's experiments,[a] we have data as to the composition of the trimmed lean meat of the carcasses of two steers about 22 months old and of two about 30 months old, as follows:

Composition of fresh lean meat of steers.

Animals.	Water.	Protein.	Fat.	Ash.
Steers 22 months old:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
No. 1	70.95	19.54	8.58	0.93
No. 4	69.07	20.11	9.83	.99
Average	70.01	19.83	9.20	.96
Steers 32 months old:				
No. 2	69.80	18.74	10.52	.94
No. 3	70.37	19.86	8.81	.96
Average	70.09	19.30	9.66	.95

These figures show very little difference in the composition of the meat of the two sets of animals, but it is to be noted that the rations fed were growing rather than fattening rations. The comparison on page 17 shows that even during the last ten months considerable growth took place.

Leyder and Pyro[b] report the following figures for the composition of lean meat from different cuts of beef. The ash is assumed as 1 per cent in every case, and the remainder of the fat-free dry matter is regarded as protein.

Composition of lean meat from various cuts of beef.

	Lean cow.	Fat ox.	Very fat cow.
Neck:	*Per cent.*	*Per cent.*	*Per cent.*
Water	76.5	78.0	76.2
Ash	1.0	1.0	1.0
Fat	1.3	1.0	2.8
Protein	21.2	20.0	20.0
	100.0	100.0	100.0
Leg:			
Water	77.1	75.0	73.3
Ash	1.0	1.0	1.0
Fat	0.9	4.0	5.8
Protein	21.0	20.0	19.9
	100.0	100.0	100.0

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[a] Maine Experiment Station, Report for 1905, vol. 2, pp. 66–69.

[b] Biedermann's Central-Blatt für Agrikulturchemie, etc., bd. 10, p. 43.

Composition of lean meat from various cuts of beef—Continued.

	Lean cow.	Fat ox.	Very fat cow.
Flank:	*Per cent.*	*Per cent.*	*Per cent.*
Water	77.5	76.8	67.8
Ash	1.0	1.0	1.0
Fat	0.8	4.3	8.8
Protein	20.7	17.9	22.4
	100.0	100.0	100.0
Tenderloin:			
Water	76.6	70.6	67.3
Ash	1.0	1.0	1.0
Fat	2.6	8.0	12.9
Protein	19.8	20.4	18.8
	100.0	100.0	100.0

They cite also the following comparison by Siegert[a] of the meat of lean and fat oxen:

Composition of meat from lean and fat oxen.

	Lean oxen.	Fat oxen.
Neck:	*Per cent.*	*Per cent.*
Water	77.5	73.5
Ash	1.2	1.2
Fat	.9	5.8
Protein	20.4	19.5
	100.0	100.0
Rib:		
Water	76.5	50.5
Ash	1.2	1.0
Fat	1.3	34.0
Protein	21.0	14.5
	100.0	100.0
Tenderloin:		
Water	77.4	63.4
Ash	1.2	1.1
Fat	1.1	16.7
Protein	20.3	18.8
	100.0	100.0

No statement is made in the abstracts above quoted regarding the preparation of the meat for analysis. The rather high percentages of fat found by Siegert suggest that his samples were of commercial "meat" rather than of lean meat proper.

Moosbruch, Meissl, and Strohmer[b] report analyses of the serratus anterior muscle from 12 fat cattle of various breeds, but give no comparison with unfattened animals. Ten of the cattle were prize animals. Their ages ranged from 25 to 84 months, and their weights from 597 to 960 kilograms. The percentage of dry matter in the meat varied from 25.01 to 40.85 (or, excluding the highest, to 32.90), and the fat from 3,35 to 18.07 (or, excluding the highest, to 12.99).

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[a] Reported also in Biedermann's Central-Blatt für Agrikulturchemie, etc., bd. 13, p. 573.

[b] Biedermann's Central-Blatt für Agrikulturchemie, etc., bd. 13, pp. 531–532.

Petersen[a] found in the lean meat of different cuts of four fat oxen percentages of fat ranging from 1.38 to 6.44, the corresponding percentages of dry matter being 23.32 and 27.05.

Beythien[b] also reports analyses of the lean meat, evidently carefully separated from the fat tissue, of different cuts of beef, pork, and mutton as sold in the Dresden market. The range in the percentage of dry matter and of fat was as follows:

Range of percentage of dry matter and fat in lean of beef, pork, and mutton.

	Dry matter.	Fat.
	Per cent.	*Per cent.*
Beef	26.02–29.57	4.64– 9.54
Pork	25.70–35.07	3.38–14.37
Mutton	25.98–27.30	5.75– 6.14

He also gives valuable data as to the proportion of lean meat, fat tissue, and bones in the cuts investigated.

Pfeiffer[c] in the course of an investigation on the distribution of fat in the body, found the following percentages of fat in the muscles of the animals named:

Percentage of fat found in the muscles of dog, rabbit, and hen.

Animal.	In fresh substance.	In dry matter.
	Per cent.	*Per cent.*
Dog:		
Fat	10.93 11.03	34.42 35.24
Lean	2.50	9.24
Rabbit:		
Fat	4.41	15.83
Lean	3.52	13.21
Hen:		
Fat	4.99 3.92	18.88 14.47
Lean	3.97	14.39

While the foregoing data are not in all respects conclusive, it is plain that to some extent in growth, but especially in fattening, there is a deposition of fat in the lean meat. It is possible that a small proportion of this may be formed in the muscular fibers themselves, but by far the larger part consists of a growth of adipose tissue between the muscle bundles, constituting, when marked, the so-called "marbling" of the meat, which adds to its tenderness and perhaps to its flavor and digestibility when cooked, and increases its nutritive value. It seems probable also that there is some increase in the soluble protein and in the extractives of the muscle, resulting in a further betterment of the quality of the meat.

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[a] Ibid., bd. 16, p. 204.

[b] Ibid., bd. 30, p. 683.

[c] Zeitschrift für Biologie, bd. 23, p. 340.

NATURE OF MEAT PRODUCTION.

The facts presented in the foregoing paragraphs enable us to formulate in somewhat more precise form the statements made at the outset regarding the nature of meat production. As there pointed out, it consists of two more or less distinct processes, viz, growth and fattening. The first of these consists essentially in an increase of the protein tissues of the body. It is relatively most active in the young animal, its rate diminishing at first rapidly and then more slowly, being apparently represented by a curve asymptotic to the zero line. The initial rate of growth and the rapidity with which it diminishes are essentially determined by the individuality of the animal, and are only to a slight degree subject to modification by the food supply, except in the negative sense that a deficient protein supply may of course limit growth for lack of material, while the same appears to be true of the ash supply. On the other hand, while there are some indications that an abundant protein supply may stimulate slightly the process of growth and lead to its earlier completion, the effect seems to be at best slight, and it remains true that the production of protein tissue is substantially a function of the animal and not of the food, and that improvement in this respect is a problem for the breeder rather than for the feeder.

Fattening, on the contrary, is a process which, in a given animal at least, is largely under the control of the feeder. Substantially, it is a function of the quantity of feed consumed by the animal in excess of the requirements for maintenance and growth, and there is lacking any definite proof that the actual storage of energy in the form of gain for a given amount of excess food is seriously affected either by the age or the individuality of the animal. Fattening, therefore, may take place at any age, although of course the greater demand for material for growth in the young animal tends to reduce the proportion of the food available for fattening.

The prime object of fattening is an improvement in the quality of the meat by the deposition of fat between the fibers of the meat, and to some extent by increasing the extractives of the meat itself. The large deposits of fat about the internal organs and under the skin are incidental to this and are to a certain extent a waste. The subcutaneous fat affords a convenient index to the quality of the meat, and of course the adipose tissue of the carcass is of some value, but it largely represents the price paid for the improved quality of the meat proper. It is not impossible that the traditions of the market may cause the process of fattening to be pushed beyond what is necessary.

CHOICE OF ANIMALS FOR MEAT PRODUCTION.

CONFORMATION.

It is a well-recognized fact that the conformation of a meat animal is a very important factor in determining his selling price, especially in the case of cattle. Thus Kennedy [a] reports the following selling prices in the Chicago market of fat steers of beef and dairy types per pound live weight:

	Cents.
2 Hereford	5.00
2 Angus	4.75
2 Holstein	3.85
2 Jersey	3.65

Similarly Mumford [b] found that feeders of high grade, as compared with those of inferior grades, graded distinctly higher when fattened, and brought correspondingly better prices.

So far as these differences in type and conformation affect the value of the finished product, they concern primarily the student of breeding rather than of feeding. Since, however, the question of the influence of breed and individuality upon the feeding capacity of animals is one of great importance, and one upon which more or less misconception exists, it seems desirable to clear the ground by pointing out here some of the chief reasons for the superiority of the meat breeds aside from any differences in feeding capacity. In doing so it will be convenient to use beef cattle for purposes of illustration, since the question has been more especially studied on these animals.

PERCENTAGE OF DRESSED WEIGHT.

The market buys on the basis of live weight, and can therefore afford to pay more for the animal containing the larger proportion of dressed carcass and the smaller proportion of relatively valueless offal. In this respect the improved meat breeds have a distinct advantage. Henry [c] gives the following summary of tests at American experiment stations bearing on this point:

Comparison of percentages of dressed weight of various breeds of cattle.

Breed.	Number of animals.	Number of stations.	Limits of dressed weight.	Average dressed weight.
			Per cent.	*Per cent.*
Hereford	11	4	63.0–68.0	65.0
Red Polled	2	1	63.8–66.5	65.2
Aberdeen-Angus	16	4	63.2–69.0	64.8
Swiss	2	1	....	64.8
Shorthorn	26	5	62.1–68.0	64.4
Galloway	6	3	62.0–66.7	63.9
Devon	7	3	62.5–65.8	63.6
Ayrshire	1	1	....	63.3
Sussex	1	1	....	63.0
Holstein	6	3	60.6–64.4	62.6
Jersey	3	2	58.7–63.9	60.5
Native	9	3	57.9–61.5	60.2

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[a] Iowa Experiment Station, Bulletin 81.

[b] Illinois Experiment Station, Bulletin 90.

[c] Feeds and Feeding, second edition, p. 375.

The same fact is reflected in the results of Mumford's experiments just referred to. The higher grades of feeders, containing the larger infusion of beef blood, dressed a higher percentage than the inferior grades. The results were as follows:

Comparison of the dressed weight of various grades of feeder cattle.

Grade.	Dressed weight.
	Per cent.
Fancy	61.62
Choice	61.52
Good	60.74
Medium	59.70
Common	59.88
Inferior	59.36

DISTRIBUTION OF FAT IN CARCASS.

As Henry [a] has pointed out, an important difference seems to exist between the dairy and beef types of cattle in this respect. He cites a number of results showing a tendency on the part of the former to the deposition of larger amounts of fat, relatively to the dressed weight, about the internal organs. That individuality may play an important part in the matter, however, is indicated by the results of later experiments by Kennedy,[b] in which two Holstein steers showed a lower percentage of internal fat (loose tallow) than either Herefords or Angus. There is no definite proof in these trials other than the better "marbling" of the meat that the beef breeds deposited more fat in the latter.

That the distribution of the fat in the carcass has much to do with the market estimate of its value is strikingly shown by experiments by Curtiss and Craig [c] upon the influence of a wide versus a narrow nutritive ratio on the growth and composition of swine. The carcasses of the lot receiving the wide ratio were regarded by Swift & Co. as too fat, yet analyses of them made by Wiley [d] failed to show any marked difference as regards the total percentages of fat and protein.

PROPORTION OF HIGH-PRICED CUTS.

It is a familiar fact, yet one the importance of which the inexperienced feeder often fails to appreciate, that different portions of the carcass show differences in composition, palatability, and nutritive value, and differ greatly in market price. The high-priced cuts are found on the back and loins, and consequently the steer which shows the best development in these regions is the more valuable animal for both the producer and the butcher, a pound of gain in these cuts being worth in the market four or five times as much as the same gain in the cheaper cuts. The same principle applies of course to other species of animals.

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[a] Ibid., p. 376.

[b] Iowa Experiment Station, Bulletin 91.

[c] Iowa Experiment Station, Bulletin 48, pp. 373–451.

[d] U. S. Department of Agriculture, Division of Chemistry, Bulletin 53.

If, therefore, there exists marked differences in the development of those parts yielding the higher-priced cuts between different breeds or individuals, it is clear that in the selection of animals for meat production this is a point of prime importance. So far as data on this point are available, however, they do not seem to indicate that the differences between breeds are as great in this respect as is ordinarily assumed to be the case. This is illustrated by the results of an experiment by Kennedy,[a] in which steers of the beef and dairy types were compared. The following table shows the percentage of rib and loin beef (the two most valuable cuts) found in each carcass, the estimated market value per pound, and the actual selling price for each animal:

Percentage of ribs and loin in carcasses of beef and dairy breeds of cattle..

	Ribs and loin.		Estimated value per pound.		Selling price per pound live weight.
			Ribs.	Loin.	
	Per cent.		*Cents.*	*Cents.*	*Cents.*
Hereford	27.22	26.48	12.5	15.0	5.00
Do	25.74		12.0	15.0	
Angus	27.65	27.18	12.5	15.0	4.75
Do	26.70		12.0	14.5	
Holstein	25.69	25.94	11.0	14.0	3.85
Do	26.18		10.0	12.0	
Jersey	26.97	25.84	10.0	12.0	3.65
Do	24.71		10.0	12.0	

While there is a slight advantage on the side of the beef breeds, it is relatively small, averaging 3.6 per cent of the figure for the dairy breeds, while the difference in price is 30 per cent.

Earlier experiments by Georgeson[b] and by Wilson and Curtiss[c] gave the following percentages of the same two cuts, showing no very marked advantage on the side of the beef breeds:

Percentage of ribs and loin in carcasses of beef and dairy breeds of cattle.

Authority.	Hereford and Angus.	Shorthorn.	Holstein and Jersey.	Native.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Georgeson		26.2		27.1
Wilson and Curtiss	28.2	27.0	27.1	
Average		26.6		

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[a] Iowa Experiment Station, Bulletin 81.

[b] Kansas Experiment Station, Bulletin 51

[c] Iowa Experiment Station, Bulletin 20.

SIZE AND QUALITY OF CUTS.

The experiments by Kennedy just cited, while not sustaining the claim that the beef breeds yield a much larger proportion of valuable cuts than do the dairy breeds, nevertheless indicate clearly the chief reason for the higher prices paid for the former, viz, that the cuts from the beef animals were esteemed to be of a higher quality and would bring more on the market. An important factor in this case was the size of the cuts. The average dressed weights of these steers were:

	Pounds.
Hereford	1,014
Angus	1,118
Holstein	847
Jersey	865

Size, thickness, and appearance are important factors in the selling price of meat. Furthermore, it is not unlikely that the "marbling"—that is, the deposition of the fat among the fibers of the lean meat—was deficient in the dairy breeds.

Finally, the fineness of fiber, tenderness, juiciness, and flavor of the meat itself all go to make up "that indefinable something described by the word 'quality,'" and which is so large a factor in determining price.

It is possible that prejudice plays some part in the relatively low price paid for animals not conforming to the meat type, but it seems unlikely that this is a large element. For the profitable production of meat the prime element is the development and fixing of breeds and strains which may be counted on to have the desired conformation and size when mature, and this is equally important whether the finishing process is carried out by the breeder or by another.

The prominence of the beef industry in the United States has caused conformation to be especially emphasized in the case of cattle, but what has been said applies equally to other species. As an illustration may be mentioned the results with Tamworth hogs at the Iowa Experiment Station[a] and experiments with the "razorback" hog by the Wisconsin station.

BREED AND INDIVIDUALITY.

While this topic is one which concerns primarily the student of breeding, it is nevertheless too important in its relation to feeding to be omitted from a discussion of that subject, especially since there appears to be considerable uncertainty and confusion of thought regarding it. While we can not expect to clear up all difficulties, we may at least hope to discover the directions in which investigation is needed.

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[a] Bulletin 48.

EARLY MATURITY.

Much stress has been laid, and doubtless rightfully, upon the importance of early maturity in meat animals, yet it is by no means clear that the word maturity has always represented the same idea. Strictly speaking, a mature animal is one which has completed its growth—that is, one in which the increase of protein tissue has reached its natural limit. In this sense, that one of two animals which reaches this natural limit first is the earlier maturing. With animals which reach substantially the same limit of size, this conception of early maturity is, of course, synonymous with a greater absolute rate of protein growth, while, if we express the latter relatively to the weight of the animal, as in previous pages, the same thing is true regardless of size.

In discussing the rate of growth, attention has already been called to the possibility of individual and breed differences in this respect. Since the main object in feeding for meat is the production of protein tissue, it is obvious that an animal which inherits a strong initial impulse to growth in this sense will be the more desirable animal, because the greater initial impulse to growth will shorten the time required for the production of a given weight of lean meat. By thus shortening the feeding period required to reach the desired weight or condition we diminish the expenditure for the simple maintenance of the animal, as well as the expense of care, etc., and the interest on the investment.

Early maturity in this sense would be nearly synonymous with a more rapid gain in weight, since the increase of the growing animal consists largely of protein tissue. As has already been mentioned (p. 29) we have no clear indication of a superiority of the meat breeds in this respect. On the other hand, there would seem to be little doubt of the existence of individual differences between animals, and it may be worth consideration whether they can be utilized in breeding.

The term early maturity, however, appears to be used also in a quite different sense, referring to the conformation of the animal rather than to completed growth. Thus, if a steer at 22 months has attained the typical beef form and reached sufficient size to meet the demands of the market, he is said to be mature. Obviously, this does not mean that he has completed his growth, but simply that he has made sufficient growth to furnish marketable meat. This conception of maturity, in other words, is commercial rather than physiological. It is important to note, however, that it involves a physiological element. A certain size of carcass as well as a certain conformation is demanded, and to reach this at an early age almost necessarily implies a greater rate of growth, whether measured physiologically by increase of protein tissue or practically by gain in weight.

It is perhaps possible to combine these two points of view into a single statement, somewhat as follows: The greater the initial impulse to growth, the sooner and the more cheaply will the animal reach physiological maturity, while if the rate of growth can be made sufficiently rapid the desired accumulation of meat, and consequent weight, may be reached before physiological maturity. In other words, the matter reduces itself to the question of rate of growth. The more rapid this is the more fully we can take advantage of the very marked assimilative power of the young animal for protein, while at the same time diminishing the relative cost for maintenance.

For these reasons, and in part also on account of changing market demands as to weight of carcass, there has been a steady tendency toward marketing meat animals at an earlier and earlier age, and it may be safely predicted that this tendency will continue until the natural limits of early maturity are reached.

FEEDING CAPACITY.

It is a well-recognized fact that very marked differences exist between different individual animals as regards the returns made for the feed consumed; but when we come to inquire into the causes of these differences we find a great dearth of definite information and a considerable variety of opinion.

Digestive power.—The superiority of one breed or animal over another as regards feeding capacity is often ascribed to a difference in the extent to which the feed is digested, although those who make this assertion often understand by digestion what is more properly termed "utilization." Undoubtedly there are differences in digestive power between different animals, but except in the case of manifestly abnormal animals they have been found to be comparatively slight and quite insufficient to account for the marked differences in production. Neither is there any evidence that the improved breeds of meat-producing animals possess any superiority in this respect over the ordinary unimproved animals.

It is to be remembered, however, that digestion experiments, for obvious reasons, have usually been made upon relatively light rations. It is possible that upon full feed the better animal would show a superiority over the poorer one in this respect which is not manifest on lighter rations, although the recorded data regarding feed requirements per unit of gain do not seem to favor this view.

Assimilative power.—By this term we may designate broadly the ability of the organism to convert the digested nutrients of the feed into body tissue. Is the good meat producer able to form from a unit of digested feed of a given kind more new tissue than can the inferior animal? In other words, is the percentage utilization of the feed above the maintenance requirement affected by the individuality of the animal? As yet there has been scarcely any scientific investigation bearing on this question. It is worth noting, however, that such of the Moeckern experiments as were made upon similar feeding stuffs with different animals show a generally good agreement as regards the utilization of the energy of the feed, although it does not appear from the accounts of the experiments whether or not the animals used differed materially in type.

In the aggregate a considerable number of breed tests of cattle, sheep, and swine have been made by the American experiment stations, the results of which have been summarized by Henry[a] so as to show the quantity of feed consumed per unit of gain. While in individual cases considerable fluctuations are to be found, nevertheless the results as a whole certainly fail to indicate any marked superiority of one breed over another in this respect, and later experiments have not given materially different results. When we come to consider the other possible factors, such as differences in live weight, in maintenance requirement, in total feed consumed, etc., we must conclude that the recorded results give no clear evidence of any specific individual or breed differences in the actual physiological processes involved in the conversion of feed into tissue, although it is equally true, of course, that they fail to prove the absence of such differences.

On the whole the probabilities seem to be that individual differences in assimilative power, in the sense in which the term is here used, if they exist at all, are not an important factor in meat production.

The maintenance requirement.—Another possible cause of the varying results obtained with different animals is variation in the amount of feed required for maintenance. It is obvious that if, of two animals receiving identical rations, one uses 50 per cent and the other 60 per cent for simple maintenance, the gains by the two, all other conditions being the same, will be in the proportion of 50 to 40. The current method of comparing the gain directly with the total feed consumed (i. e., of computing the gain per 100 pounds of feed or the feed consumed per 100 pounds of gain) entirely ignores this possible difference, which may be one of the causes operating to produce the variations in individual results in the breed tests just referred to.

The recorded results on the maintenance requirements of cattle do not seem to indicate any striking individual differences, but their number is comparatively limited. One factor in particular, which may conceivably affect the results of experiments on meat production more markedly than it would determinations of the maintenance requirement, is the greater or less degree of activity of the animal. In most maintenance experiments the latter has been necessarily more or less restricted, while under the conditions of practice it may perhaps have a considerable influence. The large expenditure of energy in all forms of muscular activity, even in simple standing, is a familiar fact. The restless, nervous animal is rarely a good feeder, because it expends too large a proportion of its feed in doing useless work, while the quiet animal that is inclined to "eat and lie down" may show much better economic results without possessing any specifically greater ability to convert surplus feed into meat. It simply has a larger surplus from a given amount of feed.

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[a] Feeds and Feeding, second edition, pp. 373, 488, 545.

Feed consumption.—Another important element in the problem, and one closely related to the preceding, is the ability of the animal to consume regularly large amounts of feed. Of two animals otherwise similar, it is clear that the one which is able to consume day after day the larger amount of feed has the advantage as a meat producer, but it is not always so clearly seen that the heavier feeder makes a relatively more profitable use of his feed. If we suppose, for example, that two fattening steers, each weighing 500 kilograms, are supplied with exactly a maintenance ration of hay, equivalent in each case, let us say, to 12,000 calories of metabolizable energy, it is clear that the one which is able to eat and digest more corn will make the more rapid gain. Let us suppose these amounts of corn consumed respectively to contain 8,000 and 6,000 calories of metabolizable energy. About 53 per cent of this energy is utilizable, and the gains will therefore be about 4,240 and 3,180 calories, respectively, and we have the following results:

Relative production on different amounts of feed.

	Steer No. 1.	Steer No. 2.
	Calories.	*Calories.*
Maintenance	12,000	12,000
Excess feed	8,000	6,000
Total feed	20,000	18,000
Gain	4,240	3,180
Total gain per 100 calories	21.20	17.67

In other words, the productive part of the ration forms a larger part of the total ration in the case of the large eater, and since all the feed must be paid for, this animal makes the more economical gain, not because he utilizes his excess feed better, but simply because he is able to consume more of it.

There is no doubt that there are marked differences between individual animals in this respect. Whether the specific meat-producing breeds as a whole possess any advantage in this respect appears doubtful in view of the results on record regarding the feed cost of gain with different breeds (see p. 46). The quality is one to which the attention of breeders has not been particularly directed, yet it is one which, it would seem, might well repay attention.

AGE OF ANIMAL.

The subject of early maturity leads naturally to a consideration of the influence of the age of the animal upon the rate and profits of meat production, a subject which requires somewhat careful consideration to avoid confusion of ideas.

In the first place it is essential to distinguish between the normal rate of growth of an immature animal and the more rapid increase in weight which may be brought about by heavy feeding. The former is not, it is true, easy to define sharply, but in a rather broad way we may say that it is the gain due to the normal rate of growth of protein tissue plus such amounts only of fat as may be regarded as necessary in a well-nourished body. We shall consider in the first place the influence of the age of the animal upon this normal rate of growth.

GAIN MOST RAPID IN YOUTH.

It has become a commonplace that animals gain most rapidly in youth. Thus the young calves experimented on by Soxhlet (see p. 13) gained per day and head from 1.65 to 2.77 pounds live weight. Wolff[a] cites the results of a feeding experiment with three calves, 14 days old, in which the daily gain in weight ranged from 1.14 to 3.38 pounds. Henry[b] cites numerous experiments with calves by different investigators in which the daily gain per head ranged from 1.43 to 2.08 pounds. While, as has just been said, these gains by growing animals are not strictly comparable with those of fattening animals, it may help us to appreciate the significance of the above figures to recall that they are scarcely inferior to the gains made by mature cattle of ten or twelve times the weight of the calves, when on full feed.

Even more striking gains are shown by young pigs. Thus Henry[c] gives the gain per day and head of sucking pigs, on the average of 12 litters, as ranging from 0.27 pound in the first week to 0.77 pound in the tenth week. Lambs show similar results. Henry[d] fed four 10-day-old lambs for twenty-one days on cows' milk and obtained an average daily gain per head of 0.46 pound. Shepperd[e] found the daily gain of four sucking lambs to range from 0.40 to 0.62 pound.

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[a] Landwirtschaftliche Fütterungslehre, p. 152.

[b] Feeds and Feeding, second edition, pp. 334–338.

[c] Ibid., p. 540.

[d] Wisconsin Experiment Station, Report for 1890, p. 12.

[e] Agricultural Science, vol. 6, p. 397. 1892.

If we compute such of the above data as admit of it per 1,000 pounds live weight, we have the following striking results:

Daily gains per 1,000 pounds live weight, by calves, pigs, and lambs of different ages.

Animals and authorities.	Average age.	Gain per 1,000 pounds live weight.
	Days.	*Pounds.*
Calves (Soxhlet)	8	21.60
	15	18.10
	21	18.40
	32	16.30
	18	17.00
Pigs (Henry)	4	78.27
	21	47.62
	67	21.51
Lambs (Henry)	21	21.40

RATE OF GAIN DIMINISHES RAPIDLY.

It is an equally familiar fact that the rate of gain per 1,000 pounds by the young animal diminishes rapidly as it grows older. The table just given illustrates this in the case of young calves and pigs. While the absolute gain per head may increase, as was the case with the pigs, the relative rate of gain diminishes.

Numerous examples may be cited to show that the same law holds for later stages of growth, although it is not in all cases easy to distinguish, from the accounts of the experiments, between the gain due to growth proper and that due to fattening. Johnson [a] reports the average daily gain in weight per head of 10 steers as follows: From birth to 1 year old, 1.94 pounds; from 1 to 2 years old, 1.36 pounds. The cattle are said to have been kept thrifty but not fattened.

Henry [b] fed calves averaging about 10 weeks old for two years with the following results:

Gains by growing cattle.

Number of animals.	Period.	Average live weight.	Gain per day.	
			Per head.	Per 1,000 pounds live weight
		Pounds.	*Pounds.*	*Pounds.*
16	Period I, 98 days	201	1.63	8.11
	Period II, 84 days	332	1.22	3.68
	Period III, 84 days	430	1.10	2.56
	Period IV, 42 days	492	0.77	1.57
12	Period V, 212 days	652	1.35	2.07
	Period VI, 64 days	878	2.46	2.80
10	Period VII, 88 days	1,007	0.82	0.81
	Period VIII, 57 days	1,079	1.25	1.16

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[a] Michigan Experiment Station, Bulletin 44, pp. 8-10.

[b] Wisconsin Experiment Station, Third Report, p. 25; Fourth Report, p. 44.

Notwithstanding the considerable fluctuations in the rate of gain, the high figures for the first period and the general decrease in the later stages of growth are evident.

Goessman[a] found the average daily gains per head of two 2-year-old steers and two yearlings on similar rations to be: Two-year olds fed one hundred and forty-four days, 1.20 pounds; yearlings fed one hundred and forty-four days, 1.60 pounds; the same yearlings fed for the succeeding one hundred and forty-four days on pasture, 0.73 pound. No statements are made as to the fattening of the animals, but the rations were only fairly heavy.

NATURE OF GAIN AT DIFFERENT AGES.

The data already given (pp. 30–33) regarding the composition and energy value of the increase at different ages show clearly one important cause, and perhaps the chief one, of the relatively rapid gain in weight by young animals. Such animals, as we have already learned, show a notable power of storing up protein, a power which diminishes rapidly with increasing age. Corresponding to this, we see that a large proportion of the organic matter stored consists of protein. Now the proteid tissues of the body are par excellence the water-holding tissues, and this fact is reflected clearly in the table, which shows the gain of very young animals to contain as much as 80 per cent of water. In other words, a pound of gain by a young animal, as compared with the same gain by a mature animal, contains much less organic matter, and this organic matter itself has a lower energy value, since it contains relatively more protein and less fat. Accordingly, as we see in the extreme case, a gain of 1 kilogram by a nearly mature animal represents the storage of over nine times as much food energy as the same gain by a very young animal.

The data are too fragmentary to permit any general statement as to the relation at different ages, but the general fact is clear. When we add to this the fact that this rapid gain in live weight by the young animal is composed largely of that which the meat producer is aiming for, viz, meat in the limited sense, the great economic advantage of the young animal becomes clear.

RELATIVE GAIN OF ENERGY.

In view of the foregoing facts, it becomes of interest to inquire whether the more rapid gain by the young animal is due wholly to the difference in the composition of the gain, or whether the growing organism has a specifically greater power to store up energy. For this purpose we may compare the rate of gain of energy per unit of live weight, somewhat as we have already compared the gain of protein. The following table contains the few available results:

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[a] Massachusetts State Experiment Station, Report for 1891, p. 107.

Relative gain of energy by animals at different ages.

Experimenter.	Animal.	Average age.	Daily gain of energy per kilogram live weight.
		Days.	*Calories.*
Sanford and Lusk	Pig	7	39.57
Wilson	do	8	29.07
Soxhlet	Calf	8	54.36
Do	do	15	50.14
Do	do	21	47.90
Tschirwinsky	Pig	114	31.72
Do	do	134	44.88
Henneberg et al	Sheep	290	14.76
Do	do	458	14.01
Do	do	521	9.50
Do	do	745	8.64
Jordan	Steer	840	3.16

The large gaps in the table are most unfortunate, but there seems to be a clear indication of a decreasing relative energy of assimilation, expressed in terms of energy, with advancing maturity. The subject is well worth further investigation, however.

GAIN PER UNIT OF FEED.

It should be clearly understood that the greater energy of assimilation just spoken of, if it be a fact, is by no means equivalent to a higher percentage utilization of the energy of the food. The facts given simply indicate that the young animal has the power to store up relatively greater amounts of matter and energy, but give no clue to the expenditure of feed energy required for this purpose. As has already been stated, no satisfactory data are on record regarding the influence of age on the percentage utilization.

In practice, however, results are measured by the gain in live weight, and this, as we have seen, represents a less amount of energy per unit in the young than in the mature animal. Consequently, even if the actual utilization of the energy of feeds of the same character is no greater in the young animal, the gain in weight per unit of feed will be greater. The experiments already cited to illustrate the rate of gain at different ages will serve to demonstrate this fact also, and to these may be added the results obtained by Wilson and Curtiss at the Iowa station.[a] In most of the experiments a variety of feeds was used and in but few of them was the dry matter of the feed determined. It will be convenient, therefore, to make the comparisons on the basis of the cost of feed per unit of gain, using this as a sort of approximate common denominator, the prices estimated for feed being generally uniform in each experiment.

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[a] Iowa Experiment Station, Bulletin 20.

The following table by Henry[a] gives the results of the experiments of Johnson, Goesmann, and Henry, and includes also averages from the records of the fat-stock shows of 1882 and 1883.

Cost of 100 pounds gain in live weight, with steers of different ages.

	1 to 12 months old.		12 to 24 months old.		24 to 36 months old.	
	Number of animals.	Cost of feed.	Number of animals.	Cost of feed.	Number of animals.	Cost of feed.
Fat-stock show, 1882[b]	9	$4.03	5	$7.98	2	$12.54
Fat-stock show, 1883	6	3.70	4	8.12	....	....
Michigan station[c]	10	1.87	10	7.37	10	9.57
Wisconsin station[d]	16	4.20	11	6.13	....	....
Massachusetts station[e]	....	....	2	7.49	2	12.38

The Iowa results, omitting the second period, on pasture, were:

Cost per pound of gain by steers at Iowa Experiment Station.

Period.	Age.	Cost per pound of gain.
	Months.	*Cents.*
I	24	5.93
III	31	6.15

As would be expected, the differences are irregular and in some cases small, and they may to a certain extent represent, particularly in the case of the figures from the fat-stock shows, the influence of increased fatness rather than of age. Nevertheless their general teaching is unmistakable.

BEST AGE FOR FATTENING.

The effect of age, as we have seen, is chiefly upon the gain of protein. While we have no evidence that the process of fattening proper is materially affected by this factor, on the other hand growth, which is largely synonymous with the formation of lean meat, goes on much less rapidly and economically as the animal approaches maturity. It is evident, as already pointed out, that the earlier the process of growth can be completed, by the selection of animals with a well-developed capacity for growth and by suitable feeding, the more economically it can be conducted. On the other hand, the process of fattening can, it would appear, be carried out equally well at almost any stage.

Fattening, however, is relatively a more rapid process than growth, and therefore should be begun later. Heavy fattening rations, containing large amounts of nonnitrogenous nutrients, even if they do not interfere with the growth of young animals, are uneconomical, tending either to overload the meat with fat or toward the accumulation of cheap internal fat, and making the animal ripe for the butcher before his capacity for the production of meat has been properly utilized. A limited market exists, of course, for fat lambs and veals; but, for the production of the bulk of the world's meat supply, it is important to utilize the capacity for growth up to a point at least approaching maturity. Such being the case, too early fattening tends to produce an animal which, even if not of inferior quality, must be maintained in a fat condition until the growth of lean meat has had an opportunity to overtake that of fat.

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[a] Feeds and Feeding, second edition, p. 369.

[b] Report of Illinois board of agriculture, 1884.

[c] Michigan Experiment Station, Bulletin 44.

[d] Wisconsin Experiment Station, Report for 1886.

[e] Massachusetts Experiment Station, Report for 1891.

On the other hand, the beginning of the fattening process may be delayed too long. To take the extreme case, it would be obviously uneconomical first to grow the animal to the full degree of maturity required and then to add a fattening period. While we have no reason to suppose that the amount of food actually expended in the production of a unit of gain would be materially greater than if the fattening were conducted during the latter part of the growing period, the expenditure for maintenance, care, interest, etc., would be simply so much added to the cost of production. Plainly the beginning of the fattening should be so timed that it will be completed by the time the rate of gain of lean meat ceases to be profitable under the existing market conditions.

The foregoing assumes, of course, that the animal is both grown and fattened by the same individual, a thing which is true in the minority of cases only. While the same general principles apply also to the fattening of purchased animals, the market is so large a factor in this operation that their application is liable to be very essentially modified or obscured entirely by speculative considerations.

CONDITION.

It is generally admitted that in the case of the nearly mature fattening animal the rate of gain in live weight decreases as the fattening progresses until a limit is reached beyond which the increase, if obtained at all, is slow and very costly. Several causes are responsible for this:

First. The maintenance requirement of the animal increases with its gain in weight, as has been shown by Kellner.[a] The capacity of the digestive organs, however, undergoes no corresponding increase, and consequently, as pointed out in a previous paragraph, not only is the amount of excess feed correspondingly reduced but its proportion in the ration is made less, so that the total feed requirement per unit of gain will be greater.

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[a] Die Landwirtschaftlichen Veruchs-Stationen, bd. 50, p. 245.

Second. The appetite of well-fattened animals not infrequently diminishes, resulting in a lessened consumption of feed. This again has a double effect, diminishing the total amount of excess feed available and reducing the proportion of excess feed to total feed.

Third. It seems probable that a unit gain in live weight toward the close of the fattening period represents a larger storage of energy than the same gain at its beginning.

For all these reasons it is natural that the "condition" of the animal—that is, its state of fatness—should have a marked effect on the rate and economy of gain. Georgeson[a] reports the following results for a lot of 3-year-old grade Shorthorn steers, the number of days given in the table meaning in each case the number from the beginning of the feeding:

Grain consumed by steers per pound of gain at Kansas Experiment Station.

Number of days fed.	Grain consumed per pound of gain.
	Pounds.
56	7.30
84	8.07
112	8.40
140	9.01
168	9.27
182	10.00

Henry[b] reports the following similar results for fattening swine:

Influence of length of fattening period on the feed consumption and gain of hogs at the Wisconsin station.

	Average weight.	Average weekly gain.	Feed eaten during week per hog.	Feed for 100 pounds of gain.	
				By weeks.	By four-week periods.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
First week	222	11.4	41	362	418
Second week	235	13.3	48	362	
Third week	246	10.5	50	475	
Fourth week	257	10.7	50	473	
Fifth week	270	13.9	51	368	461
Sixth week	281	10.1	51	510	
Seventh week	294	13.1	51	391	
Eighth week	303	8.9	51	572	
Ninth week	313	10.5	52	499	559
Tenth week	322	8.9	52	587	
Eleventh week	332	9.6	52	549	
Twelfth week	340	8.8	52	598	

On the other hand, Mumford,[c] in large-scale feeding experiments with cattle, has failed to note any such marked diminution of the gain during the later stages of feeding as has been generally found by other experimenters.

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[a] Kansas Experiment Station, Bulletin 34, p. 95.

[b] Feeds and Feeding, second edition, p. 555.

[c] Illinois Experiment Station, Bulletin 103, p. 57.

There is no sufficient evidence on record to show whether or not the actual percentage utilization of the excess feed diminishes with the advance of fattening.

FEED REQUIREMENTS FOR MEAT PRODUCTION.

The feed requirement of the meat-producing animal is of a dual character: First, there must be a sufficiency of protein to replace the amounts katabolized in the vital processes and to supply material for new growth. Second, the animal must receive an amount of potential energy in available form sufficient to maintain the normal activities of the body and to leave a surplus for storage in the form of flesh and fat.

PROTEIN.

As regards the protein supply, there is necessarily a physiological minimum, but as yet we are far from being able to formulate it with exactness. On previous pages an approximate estimate was attempted of the rate at which protein growth takes place at different ages, while from other sources some idea of the maintenance protein requirements for animals of different weights can be formed. When these two requirements were added together, however, it was found that their sum was notably less than what practical experience indicates to be necessary; and we were led to conclude that protein is required for some other purpose, possibly in connection with the more active metabolism in the growing or fattening animal.

This conclusion, however, leaves us for the present dependent upon the results of ordinary feeding experiments and of experience for our conclusions as to the protein requirements for meat production. Few or no experiments directed specifically to the determination of the protein requirements of growing animals of different species and at different ages are on record. The investigations recorded and considered on previous pages in discussing the laws of growth do, it is true, include data as to the amounts of digestible protein consumed by the animals, but while it seems probable that these were ample in most or all cases to secure a normal growth, there is no evidence that a smaller quantity of protein would not have been equally effective. A considerable amount of material along the same line awaits the compiler in the form of records of practical experiments in feeding growing animals, from which it should at least be possible to compute what amounts of protein are actually used by good feeders.

There is likewise a considerable number of experiments in which rations of different nutritive ratios have been compared in their effects on the gain in live weight of fattening animals. If in such an experiment, in which the total amounts of feed consumed do not differ widely, we find that the wider nutritive ratio has been as efficient as the narrower as regards gain in live weight, and if the gain appears to be normal in amount, there is a strong presumption that the lesser amount of protein in the wider ration was at least sufficient for the needs of the animal. If a block test shows a normal character of growth, this presumption is further strengthened. Furthermore, if we find that rations considerably poorer in protein than the current standards call for give good results in actual practice, the probability is that they contain a sufficiency of protein. Obviously data of this sort can not fix the lower limit of protein supply, but they may furnish a basis for the formulation of rules for practice.

The writer has attempted to bring together on subsequent pages what seems to be the more valuable of the readily available data, but the critical study of the entire mass of material on record is beyond the strength of a single investigator, although the task seems one well worth accomplishment.

ENERGY.

In addition to the protein necessary for maintenance and growth, the meat-producing animal requires sufficient total feed to support the bodily activities and leave a surplus for the production of a certain amount of adipose tissue. It has been shown that all the chief ingredients of the digested feed may serve for this purpose, and the amount of material thus available may be conveniently expressed in terms of energy. The most rational basis of comparison would seem to be what has been designated as net available energy, but since so few determinations of availability have been made it will be more convenient to base the discussion upon the so-called metabolizable energy, or "fuel value."

It is clear at the outset that we can not speak of the energy requirement for meat production in the same sense that we can of the protein requirement. In the latter case there is a certain natural rate of increase of protein tissue for which material must be supplied. In the former case, assuming the protein supply to be sufficient, it is, except as protein may be necessary for the more active metabolism incident to fattening, simply a question of a greater or less production of fat, or, in other words, of the rapidity of the process. This, however, is quite as much an economic as a physiological question. Is it more profitable to seek the most rapid increase possible, or will a more moderate rate of gain yield a greater return for the feed invested?

FATTENING.

In the discussion of feed requirements for meat production we have to distinguish between the standpoint of the man who buys nearly mature animals and prepares them for the market by a relatively brief fattening process, and that of the man who grows meat animals from birth. The latter, again, may market his animals in the unfattened condition as "stockers," as is largely the case with cattle in the United

States, or he may combine growth and fattening and aim to put his animals on the market in condition for the butcher, as is ordinarily done with hogs. For convenience, we may take the former case first, as being in some respects the simpler.

Under present conditions in the United States but a small proportion of the fat cattle marketed at the large centers of the trade have been grown and fattened by the same owner. Thus Mumford[a] estimates that only about 15 per cent of those marketed in Chicago are carried from birth to maturity without changing hands. The fattening of the other 85 per cent is substantially a commercial undertaking, involving a considerable element of speculation, and the time consumed in the fattening becomes an important element in determining the profit of the transaction. While the producer of "stockers" has simply to see to it that his animals secure sufficient feed to supply the demands of normal growth, the feeder of fat cattle desires to push the fattening to the limit set by considerations of cost. This he has to accomplish by the use of relatively expensive feeds; hence, the question of feed requirements and of the most complete utilization of feeds becomes a very vital one.

Substantially the same general considerations apply to mutton production as to beef production, while with swine, on the other hand, growth and fattening are more commonly combined.

PROTEIN REQUIREMENTS.

Mature animals.—Abundant data exist to show that the protein requirements of mature fattening animals as formulated in Wolff's feeding standards have been greatly exaggerated. So far as protein is concerned these standards appear to have been based upon the then prevailing views as to the source of animal fat rather than upon actual experimental investigation. Indeed, Wolff himself has demonstrated the excessiveness of the protein requirement as regards sheep. In 1890 he published[b] the results of a comparison made in 1885–86 of maize and beans as feed for fattening sheep, using two lots of two mature sheep each. After a preliminary feeding, the following results were obtained in 107 days' feeding:

Influence of protein supply on gain by mature fattening sheep.

Items.	Lot 1, fed on hay and beans.	Lot 2, fed on hay and maize.
	Kilograms.	*Kilograms.*
Weight at beginning	99.93	98.61
Weight at close	118.75	118.56
Gain	18.82	19.95
Digestible matter eaten per 1,000 kilograms live weight:		
Protein	3.26	1.81
Total digestible (fat × 2.4)	18.19	19.20

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[a] Illinois Experiment Station, Circular 79.

[b] Landwirtschaftliche Jahrbücher, bd. 19, p. 823.

The lot receiving maize is seen to have produced about the same gain relatively to the digestible matter consumed, notwithstanding the smaller amount of protein supplied. A block test tended to show a slight superiority on the part of lot 2. Similar experiments made in 1892 and published in 1896[a] gave confirmatory results, barley being compared with beans on one animal each. The following table shows the actual digestible nutrients, computed per 1,000 kilograms live weight, and the total gain for each period:

Influence of protein supply on gain by mature fattening sheep.

Period.	Number of days.	Sheep No. 1 fed on barley.			Sheep No. 2 fed on beans.		
		Total gain.	Digested per 1,000 kilograms live weight.		Total gain.	Digested per 1,000 kilograms live weight.	
			Protein.	Total nutrients.		Protein.	Total nutrients.
		Kilograms.	*Kilograms.*	*Kilograms.*	*Kilograms.*	*Kilograms.*	*Kilograms.*
III	29	1.6	1.62	14.69	2.4	3.13	16.12
IV	20	1.4	1.63	15.23	.9	2.95	16.02
V	38	4.0	2.03	17.32	3.6	3.61	16.32
Total		7.0			6.9		

In the final period of Weiske's experiments with lambs,[b] described on page 16, the animals, then 2 years old, received an exclusive hay ration from which they digested 1.22 kilograms of protein per 1,000 kilograms live weight. While no material fattening was possible on such a ration, there was still a gain of protein nearly as great per head as in earlier periods, thus rendering it probable that the protein supply was at least nearly sufficient for a moderate rate of fattening.

On the basis of these results we shall hardly go far astray if we say that 1.5 pounds of digestible protein per 1,000 pounds live weight is at least sufficient for mature fattening sheep. Whether this could be further reduced does not appear.

Lehmann[c] has reported briefly an experiment with sheep in which 400 kilograms of cotton-seed meal was fed to one lot and 450 kilograms of maize to a comparison lot, along with coarse fodder, the respective gains being 39.6 and 39.67 kilograms. The data are insufficient for a computation of the digestible matter of the rations. Funke[d] also reports an interesting case of the satisfactory fattening of mature cattle on potatoes and straw, but gives no numerical data.

Kellner's extensive respiration experiments with cattle at Moeckern have shown[e] that no larger proportion of energy is stored from protein than from fat or carbohydrates. This is equivalent to saying that the excess feed is no more efficient for fattening when it contains much protein, and the only question remaining is whether any larger proportion of the resulting gain consists of protein. To test this question, the reported results of the experiments have been grouped according to the amount of digestible protein (N.×6.25) fed, yielding the following averages per day and head:

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[a] Ibid., bd. 25, p. 175.

[b] Ibid., bd. 9, p. 205.

[c] Ibid., bd. 30, Supp. II, p. 162.

[d] Journal für Landwirtschaft, bd. 41, p. 208.

[e] Die Landwirtschaftlichen Versuchs-Stationen, bd. 53, p. 469.

Percentage of protein in gain by mature fattening cattle.

Group.	Number of experiments.	Average live weight.	Digestible protein fed.		Gain.		Protein in gain.
			Range.	Average.	Protein.	Fat.	
		Kilos.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Per cent.*
I	7	656	280- 399	343	57.2	400.2	12.50
II	14	651	400- 599	485	53.6	403.5	11.73
III	18	667	600- 799	713	87.4	440.9	16.54
IV	11	671	800- 999	894	103.3	507.8	16.91
V	10	691	1,000-1,830	1,497	108.5	521.0	17.24

Apparently the tendency of the larger protein supply in the feed was to increase somewhat the proportion of protein in the gain, even with these fully mature animals (6 to 8 years old). As noted on page 31, however, the periods covered only two to four weeks, and it may be questioned how long this gain of protein would have continued. In other words, we are again confronted with the question whether any considerable gain of protein is possible in mature animals.

The periods being short in these experiments, the effect of the different rations on the live weight can not be satisfactorily determined, and therefore the results are not fully comparable with those previously given nor with those to be considered later. It is evident, however, that very satisfactory results may be attained with mature cattle on rations containing scarcely more protein than is required for maintenance, as is evident when we compute the digestible protein in the above experiments per 1,000 kilograms live weight, viz:

	Kilograms.
Group I	0.523
Group II	.745
Group III	1.069
Group IV	1.332
Group V	2.167

Loges [a] reports the results of experiments, undertaken at Pomritz to test Kellner's conclusions, in which a nutritive ratio of 1:10.3 gave as great gains in weight with mature cattle as one of 1:5.7, but the absolute amounts of protein consumed are not stated in the abstract.

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[a] Biedermann's Central-Blatt für Agrikulturchemie, etc., bd. 31, p. 646.

Apparently from 0.75 to 1 kilogram of digestible protein per 1,000 kilograms live weight is amply sufficient to meet the requirements of fully mature fattening cattle.

Immature animals.—By far the larger share of the meat production of the United States is derived from animals that have not reached full maturity, the feeder planning, consciously or unconsciously, to take advantage of the capacity for growth of the immature animal and thus to combine to a certain degree growth and fattening.

For years feeders in the corn belt of the United States have been fattening nearly mature cattle, sheep, and hogs chiefly on Indian corn, using rations that can hardly have had a narrower ratio than 1:10, and must often have been much wider. It would be foolish to assert that these feeding practices have always been the most rational. There is little doubt that more and better, and possibly cheaper, meat might often have been produced had more protein been supplied, but it nevertheless remains true, in a broad way, that at least fairly satisfactory results have been and are being reached on rations containing scarcely half the protein called for by the Wolff standard for mature animals. At the same time, accurate numerical data as to the rations fed in practice are not easily obtained.

The earliest American experiments on the protein requirements of fattening cattle of which the writer has knowledge are those of Jordan [a] in 1881–1885, in which the value of cotton-seed meal as an addition to corn meal was tested. The following tabulation gives such of the results of the experiments as bear on the present discussion. When necessary, the digestible protein of the rations has been computed by the writer, while as an approximate measure of the total quantity of food (energy) in the rations their "production values" have been computed from Kellner's table.

Comparison of corn-meal with corn-meal and cotton-seed-meal rations for fattening cattle.

	Per day and 1,000 pounds live weight at beginning of period.	
	Corn-meal ration.	Corn-meal and cotton-seed-meal ration.
1881–82.		
Eastern farm,[a] ninety-seven days:		
Digestible protein .... pounds..	1.06	2.08
Production value .... calories..	13,620	12,730
Gain in weight .... pounds..	1.28	1.84
Central farm, eighty-four days:		
Digestible protein .... do....	1.24	2.17
Production value .... calories..	16,070	12,330
Gain in weight .... pounds..	1.135	1.602
Relative gains .... do....	100	149
Relative gains on preliminary feeding .... do....	100	144

[a] Pennsylvania State College, Bulletins 6 and 10; Report for 1886, p. 175.

Comparison of corn-meal with corn-meal and cotton-seed-meal rations for fattening cattle—Continued.

		Per day and 1,000 pounds live weight at beginning of period.	
		Corn-meal ration.	Corn-meal and cotton-seed-meal ration.
1882–83.			
First period, forty-nine days:			
Digestible protein	pounds..	1.09	1.80
Production value	calories..	14,220	10,710
Gain in weight	pounds..	1.675	1.172
Second period, forty-two days:			
Digestible protein	do....	1.16	1.87
Production value	calories..	14,310	11,420
Gain in weight	pounds..	1.767	1.557
1883–84.			
2-year-olds, seventy-seven days:			
Digestible protein	pounds..	1.38	2.20
Production value	calories..	15,870	13,440
Gain in weight	pounds..	2.42	2.79
3-year-olds, seventy-seven days:			
Digestible protein	do....	1.26	2.10
Production value	calories..	13,900	12,180
Gain in weight	pounds..	1.49	1.51
4-year-olds, seventy-seven days:			
Digestible protein	do....	1.31	2.15
Production value	calories..	13,480	12,250
Gain in weight	pounds..	1.54	[b].86
1884–85.			
2-year-olds, sixty-three days:			
Digestible protein	pounds..	1.60	1.74
Production value	calories..	13,340	10,280
Gain in weight	pounds..	2.00	2.05
3-year-olds, sixty-three days:			
Digestible protein	do....	.94	1.63
Production value	calories..	12,500	10,050
Gain in weight	pounds..	1.76	1.97

Assuming, according to Kellner, a requirement of 6 pounds of starch equivalent, equal to 6,426 calories production value, for maintenance, the experiments of 1881–82 and 1882–83 show an advantage on the side of the higher protein, but the difference is much less marked in 1882–83, when the cattle are said to have been older, although the ages are not stated.

The experiments were continued by Frear[c] in 1885–86 on the same general plan, but with greater elaboration of detail. Two lots of two 3-year-old steers received per 1,000 pounds live weight rations containing the following amounts of digestible protein per day as determined by digestion experiments: Steers 2 and 3, Period II, 1.61 pounds; Period III, 1.69 pounds. Steers 1 and 4, Period II, 0.79 pound; Period III, 0.93 pound. The apparent advantage was on the side of the low protein rations, but the periods were short and there was no close agreement between the individual animals.

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[a] Average of two periods in which the rations of the two lots were interchanged.

[b] Animals not thrifty.

[c] Pennsylvania State College, Report for 1886, p. 180.

Two lots of 2-year-old steers gave the following results per day per 1,000 pounds live weight:

Gains by 2-year-old steers on a corn-meal ration and on a cotton-seed meal ration.

	Results with corn-meal ration.	Results with cotton-seed-meal ration.
Digestible protein....pounds..	1.13	1.73
Production value....calories..	14,980	10,730
Gain in weight....pounds..	1.314	1.392

In almost every case the gain per unit of "production value" is greater on the high-protein ration, especially if we deduct the probable maintenance requirement and make the comparison on the basis of the excess feed. We may fairly attribute this greater increase to a greater growth of meat, with its large percentage of water, made possible by the larger protein supply. Apparently a ration of from 1 to 1¼ pounds of digestible protein (N.×6.25) per day per 1,000 pounds live weight is insufficient to insure the normal growth of meat in steers 2 to 3 years old.

Some comparatively recent experiments at the Missouri Experiment Station[a] tend to confirm these early Pennsylvania results. They have thus far been published only in outline,[b] and in particular the weights of the animals are lacking, so that the comparison per 1,000 pounds live weight can not be made.

Results in feeding steers at the Missouri Experiment Station.

Animals and rations.	Digestible protein of ration.	Production value of ration.	Gain in weight per day.
	Pounds.	*Calories.*	*Pounds.*
Yearling steers:			
Timothy hay....	0.45	7,284	[c] 30.8
Corn stover and clover hay....	.93	7,723	[c] 58.4
Yearling steers, 1899:			
Corn and timothy hay....	.57	8,624	0.64
Corn stover and clover hay....	.93	8,968	0.88
Corn and cowpea hay....	2.01	11,323	1.54
Yearling steers, 1900:			
Corn and timothy hay....	.69	10,097	1.00
Corn and clover hay....	1.37	11,541	2.00
Corn stover and clover hay....	1.15	11,166	1.35
2-year-old steers, 1899–1900, full feed:			
Corn and timothy hay....	1.45	20,040	1.69
Corn and cowpea hay....	2.30	22,942	2.64
Corn, clover hay and corn stover....	1.71	21,577	1.94
2-year old steers, 1900–1901, full feed:			
Corn and timothy hay....	1.51	20,689	1.97
Corn and clover hay....	2.17	24,814	2.84
Corn and cowpea hay....	2.78	25,637	2.84
Clover hay and corn stover....	1.92	23,466	2.85
Clover hay and wheat straw....	1.97	22,919	2.68

If we may assume an average live weight of 700 pounds per head for the yearlings and of 1,000 pounds per head for the 2-year-olds, the minimum requirement for 2-year-olds would seem to be somewhat higher than that indicated by the Pennsylvania experiments, viz, more than 1.5 pounds, while that for yearlings is apparently fully 2 pounds per day per 1,000 pounds live weight.

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[a] Monthly Bulletin Missouri Board of Agriculture, September, 1901; University of Missouri, Circular of Information No. 11.

[b] Further data regarding the experiments on yearlings have appeared in Bulletin 75 of the Missouri Station.

[c] Total for experiment.

Mumford[a] has compared a ration of corn, timothy hay, and corn stover with rations in which on the one hand clover hay was substituted for the corn stover and timothy hay, and on the other hand gluten meal replaced part of the corn, the animals being native steers, weighing about 970 pounds, and of common to medium quality, fed in carload lots. The bulletin states the total feed consumed during the eighteen weeks of the experiment. The average daily ration should therefore be compared with the live weight at the middle of the experiment. Using average figures, the writer has computed the digestible matter and production values of these rations as follows:

Feed consumed per 1,000 pounds live weight.

Lot.	Ration.	Dry matter.	Digestible matter in ration.				Production values.
			Protein.	Carbohydrates.	Fat.	Total (fat × 2.25).	
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Calories.*
1	Corn and clover hay	23.86	1.79	14.81	0.85	16.72	17,350
2	Corn, timothy hay, and corn stover	22.19	1.24	14.50	.75	16.20	16,480
3	Corn, gluten meal, timothy hay, and corn stover	21.02	1.49	13.01	.88	14.97	15,160

These rations produced the following average daily gains:

Average daily gains per head and per 1,000 pounds live weight.

	Per head.	Per 1,000 pounds live weight.
	Pounds.	*Pounds.*
Lot 1	2.510	2.21
Lot 2	1.858	1.70
Lot 3	2.268	2.01

Assuming a maintenance requirement of 6 pounds of total digestible matter per 1,000 pounds live weight, or 6,426 calories production value, the excess feed per pound of gain was as follows:

Excess feed per pound of gain.

	Excess feed.	
	Weight.	Production value.
	Pounds.	*Calories.*
Lot 1	4.66	4,940
Lot 2	5.71	5,910
Lot 3	4.21	4,340

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[a] Illinois Experiment Station, Bulletin 83.

It appears evident that the 1.24 pounds of protein per 1,000 pounds live weight in the ration of lot 2 was insufficient for the maximum increase. Lot 1 gained notably more than lot 3, but also consumed more feed, so that the excess feed of lot 3 appears to have been somewhat more efficient than that of lot 1, while in both cases it gave much better results than with lot 2.

In a later experiment by the same investigator,[a] comparing methods of preparing feeds, in which choice 2½-year-old cattle were fed in lots of 10 or 15 each for one hundred and eighty-six days, results were obtained bearing on the subject under discussion. The published figures do not admit of a ready computation of the energy values of the rations, but from data kindly furnished by Professor Mumford the average digestible matter per 1,000 pounds live weight at the middle of the experiment has been computed. The table includes also the average daily gain of live weight per head and per 1,000 pounds.

Average digestible matter and gain per head and per 1,000 pounds live weight.

Lot.	Feeds.	Digestible matter per 1,000 pounds live weight.			Daily gain.	
		Protein.	Carbohydrates + (fat × 2.25).	Total.	Per head.	Per 1,000 pounds live weight.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	Corn meal, gluten meal, oil meal, silage, and clover hay	1.71	13.63	15.34	2.34	1.90
2	Ear corn, gluten meal, oil meal, and clover hay	1.99	15.49	17.48	2.33	1.85
3	Ear corn broken, clover hay	1.49	15.52	17.01	2.08	1.73
4	Corn meal, gluten meal, oil meal, and clover hay	1.90	14.84	16.74	2.38	1.95
5	Corn meal, gluten meal, oil meal, and chaffed hay	1.86	14.48	16.34	2.33	1.86
6	Corn and cob meal, gluten meal, oil meal, and clover hay	1.76	15.46	17.22	2.32	1.87
7	Corn and cob meal, gluten meal, oil meal, and clover hay	1.79	15.87	17.66	2.45	2.00
8	Ear corn, oil meal, shock corn, and clover hay	1.67	15.40	17.07	2.08	1.69
9	Shelled corn, gluten meal, oil meal, and clover hay	2.13	14.86	16.99	2.02	1.66
10	Shelled corn, gluten meal, oil meal, and clover hay	2.13	14.88	17.01	1.99	1.64
	Average of lots 1, 2, 4, 5, 6, and 7	1.84	14.96	16.80	2.36	1.90
	Average of lots 3 and 8	1.58	15.46	17.04	2.08	1.71
	Average of lots 9 and 10	2.13	14.87	17.00	2.01	1.65

The daily gain approaches 2 pounds per 1,000 pounds live weight, and is notably uniform except in lots 3, 8, 9, and 10, which show distinctly lower results. Mumford compares especially lots 2 and 3, receiving rations most nearly comparable as to kind of feed, and attributes the difference to the lower protein content of the ration of lot 3. The ration of lot 8, too, was not widely different from that of lot 3. On the other hand, lots 9 and 10, which also gave smaller gains, consumed more protein than any of the others. The pen of lot 9 differed from the others in being unpaved and muddy, which may possibly have influenced the gains, but there is no evident reason for the lower gains of lot 10. On the whole, however, the results seem to indicate that to obtain the maximum growth cattle of this age require more than 1.5 pounds of digestible protein per 1,000 pounds weight, agreeing in this respect with the earlier experiment.

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[a] Illinois Experiment Station, Bulletin 103.

Scheneidewind [a] reports some interesting results of experiments at Lauchstädt, undertaken to test Kellner's conclusions as to the protein requirements in fattening. Two experiments were made, one on two lots of 7 East Prussian cattle 24 months old, and one on two lots of 10 Simmenthal cattle 18 months old, each experiment being divided into two periods. The results were as follows, per 1,000 pounds live weight per day:

Daily gains from feeding a high-protein and a low-protein ration compared.

	Results with—	
	Low-protein ration.	High-protein ration.
2-YEAR-OLD CATTLE.		
Period I, one hundred and thirty-three days:	*Pounds.*	*Pounds.*
Digestible protein	2.0	3.0
Total nutrients	17.0	18.0
Gain	2.57	2.46
Period II, sixty-three days:		
Digestible protein	1.58	2.64
Total nutrients	15.80	15.80
Gain	2.23	2.08
18-MONTHS-OLD CATTLE.		
Period I, one hundred and thirty-three days:		
Digestible protein	2.0	3.0
Total nutrients	17.0	18.0
Gain	3.08	2.95
Period II, sixty-three days:		
Digestible protein	1.58	2.64
Total nutrients	15.80	15.80
Gain	2.33	2.76

In a general way, these results are in accord with those previously quoted in indicating a protein requirement in the neighborhood of 1.5 pounds or perhaps 1.75 pounds per 1,000 pounds live weight for 2-year-old cattle, and of at least 2 pounds per 1,000 pounds live weight for younger animals. Kellner [b] recommends 2 pounds per 1,000 pounds live weight for 2 to 3 year old cattle.

Influence of protein supply on quality of meat.—In discussing the influence of the fattening process on the composition of the lean meat, it has already been shown that there appears to be usually an increase in the soluble protein and extractives. There is no clear evidence that an abundant supply of protein in the feed favors this increase. In view, however, of the storage of nitrogen in mature animals, shown especially by Kellner's results as summarized above, we shall be inclined to answer the question in the affirmative pending further experiments. At the same time, it may be questioned whether this is a very important factor in determining the commercial quality of meat.

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[a] Landwirtschaftliche Jahrbücher, bd. 31, p. 941.

[b] Loc. cit., p. 460.

TOTAL FEED.

Assuming that the feeder has made such a selection of feeds as will insure a sufficient protein supply, the question of the most profitable amount of feed is of the utmost importance. Shall he seek to secure the most rapid gain possible, or will a more moderate rate of fattening yield a greater return on the investment? Obviously this question is not capable of a categorical answer unless all the economic conditions are stated, but it may be profitable to indicate some of the conditions which will determine the answer.

Different quantities of the same ration.—As the simplest case, we may consider first the effect of feeding varying amounts of the same feeding stuff or mixture of feeding stuffs—as might be done, for example, by the use of "cut feed." In this way we may avoid the complications incident to the varying availability and utilization of different feeds.

The percentage utilization of the metabolizable energy of a feeding stuff for meat production is probably constant within at least quite a wide range as regards the amount fed. Each additional unit of energy consumed, then, will produce the same actual storage of energy in the tissues of the animal. A certain amount of the feed, however, is required simply to maintain the animal. Consequently, as has already been shown in discussing the influence of the individuality of the animal as manifested in its maintenance and its feed consumption, the larger the amount of feed eaten the larger is the proportion of it which is available for production and the greater the gain per unit of total feed. Under these conditions it is plain that the more liberal feeding is the more economical, and that it is desirable to stimulate the feed consumption of the fattening animal within reasonable limits. To put the matter in another way, the more rapid production due to heavier feeding, by hastening the completion of the fattening process, shortens the time during which the maintenance ration must be paid for.

It is quite possible, however, that there are limitations to this principle. In the first place, it is obvious that if the feed consumption is stimulated to the point of producing digestive or other disturbances, so that the animal is "off feed," the resulting disturbance and lessened consumption of feed may far outweigh any advantage from the increased amount eaten. It is the regular, uniform eater that is likely to be the profitable animal, rather than the one with a capricious appetite.

But even if this danger be avoided, it is not certain that the maximum possible consumption of feed is the most profitable. Kellner[a] found the digestibility of a mixed ration to decrease somewhat as the amount fed increased. Similar results have also been obtained by Weiske, Kühn, and Jordan, although the result is contrary to current tradition. If this proves to be the case with full feeding in general, it is equivalent to a decrease in the metabolizable energy of the feed. Consequently, even though the gain per unit of metabolizable energy might remain the same, the gain per unit of added feed would decrease. Whether, however, the diminution of the percentage digestibility is sufficient to set a limit to the advantage of an increased consumption of feed remains to be shown. Morgen,[a] however, reports experiments on sheep in which very heavy rations actually produced smaller gains in live weight than lighter ones.

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[a] Loc. cit., p. 47.

Finally, it should be remembered that it is the actual gain of potential energy by the animal which we believe to bear a constant relation to the food energy. It has been repeatedly pointed out that the gain in live weight is a very uncertain indication of the amount of energy stored up. It is quite conceivable that the larger gain to be expected on the heavier ration may contain less water and more dry matter, or less protein and more fat, than that produced on the lighter ration, and that consequently the increase in weight may not be proportional to the increase in feed. In that case, unless the higher quality of the gain were recognized in the market, the economic advantage attaching to heavier feeding, as just pointed out, would be diminished or even wiped out.

Varying amount of concentrates.—The general considerations developed in the foregoing paragraph apply directly only to different amounts of the same feed or mixture. In practice these conditions may be obtained with swine, which may be fed exclusively on concentrates, but not with cattle and sheep, requiring a mixed ration of concentrates and fodder. Even with these animals, however, the same general line of reasoning applies to those cases in which the productive part of the rations consists of a concentrate or a mixture of concentrates, the coarse fodder not exceeding the maintenance requirement. The case is the same as that supposed for illustration on page 47. When we come to compare light or medium rations with heavy ones, however, other considerations enter in. Since the coarse fodders are usually relatively cheap, and since ruminants are adapted by nature to consume large quantities of them, a light or medium ration for these animals will usually contain a considerable proportion of roughage. When such an animal is to be put on full feed, physical considerations of bulk forbid the simple increase of both coarse fodder and concentrates in the original proportions, but instead compel a substitution of concentrates for coarse fodder until, in extreme cases, but a minimum of the latter is left and the animal is brought into the abnormal condition of subsisting largely on concentrates.

In the first place, speaking in general terms, a given weight of a concentrate contains more metabolizable energy (fuel value) than the same weight of a coarse fodder, and furthermore, a larger percentage of this larger amount is utilizable in the form of gain. Expressed in more current terms, a pound of concentrates supplies more digestible matter than a pound of coarse fodder, and this digestible matter is more efficient in producing gain.

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[a] Fütterung and Schlachtergebnis, pp. 22 and 33.

In the second place, the substitution enables the animal to consume a greater amount of digestible matter, owing to the smaller bulk of the ration, and this leaves a larger supply over the maintenance requirement to be applied to productive purposes. A steer weighing 1,000 pounds would hardly consume much more than 20 pounds of hay per day, while if the hay were reduced to a minimum of, say, 6 pounds, it would not be difficult to feed with this 16 to 18 pounds of concentrates. On the basis of the figures for timothy hay and corn meal given in Bulletin 71 (revised edition) of the Pennsylvania Experiment Station, page 12, we may make the following comparison of these two rations, assuming as the maintenance requirement 7,350 calories of net available energy. The first column shows the theoretical results on the hay ration, the second those which would be obtained by substituting 14 pounds of corn meal for an equal weight of hay, and the third the effect of further increasing the corn meal.

Comparison of rations composed of timothy hay and of timothy hay and corn meal.

Items.	Ration I, 20 pounds of timothy hay.	Ration II, 6 pounds timothy hay and 14 pounds corn meal.	Ration III, 6 pounds timothy hay and 18 pounds corn meal.
	Calories.	*Calories.*	*Calories.*
Net available energy	9,780	21,250	26,480
Maintenance	7,350	7,350	7,350
Excess over maintenance	2,430	13,900	19,130
Computed gain [a]	1,286	9,529	13,113
Gain per pound of feed	64	476	656
Gain per 100 calories net available energy	13	45	50

[a] Percentage of available energy utilized: For timothy hay 52.93 and for corn meal 68.55.

It is evident that if a calorie of net available energy costs the same in the two feeds there is a great advantage in the substitution of the corn meal for the hay and a further advantage in increasing the amount of corn meal.

The relative cost of grain and hay will, of course, vary from time to time, but as an illustration we may take the prices used by Mumford in Bulletin 83 of the Illinois Experiment Station, viz, $23 per ton for corn meal and $14 per ton for timothy hay. We should then have the following results: Cost of ration per day—Ration I, 14 cents; Ration II, 20.3 cents; Ration III, 24.9 cents. Cost of 1,000 calories gain, respectively, 10.89, 2.13, and 1.90 cents.

On this supposition, taking as the basis of computation the figures on page 12 of Pennsylvania Bulletin 71 (revised edition), if a ton of corn meal is worth $23 for maintenance or production, respectively, a ton of timothy hay would be worth $11.08 for maintenance and $8.55 for production. If, now, we assume the cost of the hay to fall to $7 per ton, that of corn meal remaining unchanged, the energy supplied by the hay, either for maintenance or production, will cost less than that supplied by the corn meal. Nevertheless, when we make the computation, we find that the heavy ration would still give the cheaper gain, the computed cost of 1,000 calories of gain being: Ration I, 5.44 cents; Ration II, 1.91 cents; Ration III, 1.74 cents. That is, even at the relatively high price assumed for corn meal as compared with hay, the large amount of the former which can be consumed gives it the advantage. Even if we assume it possible to feed 30 pounds of hay per day, the cost of 1,000 calories of gain still remains much higher than on the grain rations, viz, 2.71 cents.

Standards.—It is clear from the foregoing that under ordinary conditions mature or nearly mature fattening animals should be fed as heavily and pushed as rapidly as the capacity of the animals and the skill of the feeder will permit. This conclusion was reached long ago by practical feeders, so that the results of experience and of scientific investigation appear quite in harmony. Such an intensive feeding can be effected only by a free use of concentrated feeds, and our computations in the preceding paragraph indicate clearly that, unless concentrates are very expensive as compared with coarse feed, it is economy to substitute the former for the latter to the largest extent possible.

Under these conditions it is evident that there is very little significance in a feeding standard in the ordinary sense, so far at least as the amount of feed is concerned. It may, it is true, serve to afford a basis for preliminary computation of the amount of feed required for a season's feeding, if this is of any importance, but in actual feeding the problem is to induce the animals, by means of the art of the skilled feeder, to consume large amounts of feed without injury to their appetites or digestive capacity, and this is largely a question of the individuality of the animal or lot. The one thing to be kept in mind is to see that the supply of protein in the ration is sufficient to insure the normal growth of protein tissue, since this causes a relatively rapid increase in weight.

GROWTH.

The fattening of mature or nearly mature animals which we have been considering is essentially an improvement in the quality of the meat, and may be characterized as largely a commercial undertaking. As was insisted at the outset, the production of meat in the stricter sense is possible only during growth, and is relatively more rapid the younger the animal. The question of feed requirements for growth is therefore one of prime importance in meat production, and from a general point of view is of equal importance whether the processes of growth and fattening are carried on by one owner or by separate parties.

PROTEIN REQUIREMENTS.

Growth, as we have seen, being largely synonymous with increase of protein tissue, a knowledge of the amount of protein required for normal growth is of the highest importance. As has been pointed out (page 29), however, we are not yet able to formulate any general statement on this point, nor have we any specific experimental data as to the minimum protein requirements at different ages, but must content ourselves with such empirical data as the records of successful feeding experiments afford.

Protein requirements of cattle.—The experiments tabulated earlier in discussing the rate of growth include three series of experiments upon young calves, viz, those of Soxhlet, DeVries Jzn, and Neumann, the feed being whole milk in the first case and skim milk in the last, while De Vries Jzn's experiments include both, in some cases with the addition of starch to the skim milk.

We may perhaps assume that the amount of whole milk consumed by the calf gives an approximate measure of its requirements. The natural conclusion from this would be that the skim-milk calves tended to receive an excess of protein. Computing the results per 1,000 pounds live weight and grouping by ages we have the following summary:

Protein supply and protein gain of calves.

Authority.	Animal.	Period.	Age.	Digestible protein per 1,000 pounds live weight.	Gain of protein per 1,000 pounds live weight.
			Days.	*Pounds.*	*Pounds.*
Soxhlet	A	I	18	4.24	2.80
	A	II	32	4.29	2.71
	B	I	15	5.50	3.55
	B	II	21	4.77	3.02
	C	I	8	5.71	3.99
	Average		19	4.90	3.22
De Vries Jzn	B	I	38	4.93	2.12
	C	I	37	5.61	2.28
	D	I	45	3.48	2.17
	Average		40	4.67	2.19
	A	I	50	5.21	1.50
	A	II	65	4.48	1.72
	A	III	74	4.26	1.27
	C	II	64	4.37	1.21
	D	II	63	2.84	1.21
	D	III	74	2.79	1.27
	Average		65	3.99	1.36
	A	IV	100	3.32	1.19
Neumann	First series	I	40	6.30	2.95
		II	45	5.94	2.42
	Second series	I	57	5.70	2.28
		II	62	5.36	1.61
		IV	69	5.28	1.82
	Average		55	5.72	2.22

Neumann used skim milk exclusively, giving somewhat heavier rations than in the other cases, but did not obtain a materially greater gain of protein by the animals than did the other experimenters, if we except the second group of the experiments by De Vries Jzn.

On older cattle we have the following results of Jordan's experiments. The data given are those reported for animals Nos. 2 and 3.

Protein consumed by cattle.

Period.	Average age.	Digestible protein per 1,000 pounds live weight.
		Pounds.
First fifteen months:		
Steer No. 2	About 15 months	1.65
Steer No. 3	do	1.12
Last twelve months:		
Steer No. 2	About 28 months	1.68
Steer No. 3	do	.95

Steer No. 2 gained weight more rapidly than steer No. 3 during the first fifteen months, but the reverse was the case during the last twelve months.

To the foregoing results the general averages estimated in the paragraphs on fattening may be added, and we have the following as the amounts of protein which have been supplied to cattle at different ages with apparently satisfactory results:

Amounts of protein supplied to cattle by various experimenters.

Age.	Experimenter.	Digestible protein per 1,000 pounds live weight.
		Pounds.
19 days	Soxhlet	4.90
40 days	De Vries Jzn	4.67
55 days	Neumann	5.72
65 days	De Vries Jzn	3.99
100 days	do	3.32
1 year	Waters	2.00
1½ years	Schneidewind	2.00
2 years	do	1.50–1.75
2 years	Waters	>1.50
2½ years	Jordan and Frear	>1.33
2½ years	Mumford	>1.50
6–7 years	Kellner	.75–1.00

While these figures must be interpreted in a very broad way, they show clearly a decreasing protein requirement per 1,000 pounds weight with advancing maturity.

The results tabulated above have been platted graphically on figure 1, being represented by the sign x, while the upper curve of the diagram represents the Wolff-Lehmann standards on the same scale.

It is hardly a mere coincidence that when thus platted the above results give a curve quite similar to that previously found as representing the rate of growth. Furthermore, it is of considerable interest to find that these results, worked out independently, and to a considerable extent from American data, correspond quite closely with the Wolff-Lehmann standards for growing beef cattle, as appears from a comparison of the figures and from the corresponding curve in the diagram.

Protein requirements of sheep.—But few satisfactory data regarding the protein requirements of sheep appear to be available. A certain amount of protein is of course required for the growth of the wool. On the basis of a number of results by Henneberg and his associates, this may be estimated at about 0.15 pound of protein per 1,000 pounds live weight per day. While this, although small in itself, is considerably greater than the accepted estimates for the growth of hair in cattle, yet it is hardly sufficient to justify the somewhat current notion that sheep require a considerably greater protein supply than cattle.

Wolff based his standards for growing sheep largely upon experiments of his own.[a] Somewhat later the experiments by Weiske[b] on the growth of lambs, which have been cited on previous pages, afforded confirmation of Wolff's results. Wolff's experiments included only determinations of the digestibility of the rations and the gain in live weight; Weiske's included also determinations of the nitrogen balance, which showed an apparently normal rate of growth. The following are the amounts of digestible protein per 1,000 pounds live weight consumed in the two series of experiments, the results being arranged in order of age:

Protein consumed by sheep.

Age.	Digestible protein per 1,000 pounds live weight.	Experimenter.
	Pounds.	
4 to 5 months	3.76	Weiske.
5 to 6 months	3.26	Do.
5 to 6 months	3.16	Wolff.
6 to 7 months	2.78	Weiske.
6 to 8 months	2.96	Wolff.
7 to 9 months	2.76	Weiske.
8 to 9 months	[c]1.87	Wolff.
9 to 10 months	2.38	Weiske.
10 to 11 months	2.30	Do.
9 to 12 months	[c]1.38	Wolff.
11 to 12 months	2.16	Weiske.
12 to 14 months	1.96	Do.
12 to 14 months	1.61	Wolff.
14 to 15 months	1.92	Weiske.
24 months	1.22	Do.

Apparently the amount of protein fed in the above experiments was ample, but there is nothing to show whether smaller amounts would have been equally sufficient or not, the inferior growth observed by Wolff in two cases being attributable, in part at least, to a deficient amount of total feed.

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[a] Landwirtschaftliche Jahrbücher, bd. 2, p. 221. Compare also Armsby, Manual of Cattle-Feeding, pp. 448–451.

[b] Landwirtschaftliche Jahrbücher, bd. 9, p. 205.

[c] Believed by the author to be too low, owing to the inferior quality of the hay fed and consequent small amount eaten.

In the other experiments with lambs and sheep referred to on previous pages, considerably larger amounts of protein were fed, so that no indications are to be derived from them as to the lower limit of protein supply. The writer has not yet been able to compile the data of American experiments bearing on this point.

Protein requirements of swine.—The experiments by Sanford and Lusk and by Wilson on sucking pigs afford an instructive example of the capacity of young animals to consume and utilize protein. On the average of these experiments the amounts of protein consumed daily, computed per 1,000 pounds live weight, and the amounts retained in the body were as follows:

Protein supply and protein gain of pigs.

Experimenter.	Average age.	Protein digested per 1,000 pounds live weight.	Protein stored in body per 1,000 pounds live weight.
	Days.	*Pounds.*	*Pounds.*
Sanford and Lusk	7	13.68	5.86
Wilson	8	14.71	5.93

Considerable emphasis has been laid upon the necessity of a liberal protein supply for the pig in view of his rapid growth. A large number of experiments, for example, are cited by Wolff, in his classic compilation,[a] showing the much greater feed economy incident to the use of rations with a narrow nutritive ratio for young pigs. Altogether similar results were reached in a compilation[b] of American pig-feeding experiments prepared by the writer for the United States Department of Agriculture.

The well-known experiments by Sanborn, Henry, and others upon the influence of extreme rations on the proportion of fat and lean in the carcass are too familiar to need repetition here. They have served to call attention sharply to the need for protein in the feed of young pigs, but because the experimental conditions were purposely made extreme it seems possible that they have given rise to exaggerated notions regarding the actual amount of protein required and the effect of practicable variations in rations. Some of the more recent experiments of this class, at any rate, tend to throw doubt upon the validity of the very high protein requirements for pigs formulated in the Wolff-Lehmann standards.

Attention may be called particularly to some comparatively recent experiments at the Wisconsin and Iowa experiment stations upon the influence of wide and narrow nutritive ratios upon the character of the carcass. Some of the main results of the Wisconsin experiments are tabulated below.

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[a] Die Ernährung der Landwirtschaftlichen Nutzthiere, pp. 465–496.

[b] Unpublished manuscript.

Influence of protein supply on growth of pigs.

	Number of animals.	Length of experiment.	Average age at beginning.	Average weight at beginning.	Average weight at middle of experiment.	Digestible protein per day per 1,000 pounds live weight.	Total nutrients per day per 1,000 pounds live weight.	Average gain.	
								Per head.	Per 1,000 pounds live weight.
Seventeenth Report, page 12:		*Days.*	*Days.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Lot 1	8	126	65	65	143.4	2.54	24.17	1.24	8.670
Lot 2	8	126	65	65	139	5.07	23.11	1.17	8.425
Eighteenth Report, page 25:									
Lot 1	5	84	184	133.2	173.6	2.72	25.12	.96	5.55
Lot 2	5	84	182	133.6	157.8	3.81	19.57	.58	3.65
Eighteenth Report, page 44:									
Lot 1	5	210	118	48.1	119.6	4.72	19.67	.75	6.27
Lot 2	5	210	116	47.1	106	2.29	24.42	.63	5.94
Nineteenth Report, page 17:									
Lot 1	6	144	125	68.4	128.7	5.40	22.57	.837	6.504
Lot 2	7	144	128	68.4	120.4	1.90	22.70	.540	4.485
Twenty-first Report, page 25:									
Lot 1	3	110	(?)	52.3	74	2.97	31.70	.394	5.32
Lot 2	3	110	(?)	53.7	114	3.52	25.31	1.097	9.62
Twenty-first Report, page 32:									
Lot 1	3	98	240	225	287	3.55	19.81	1.262	4.40
Lot 2	3	98	240	213	267	2.19	19.90	1.099	4.12

The data of the block tests which were made in each case afford data for the following notes:

Seventeenth Report, page 12.—The carcasses of lot 1 (wide ration) showed the greater thickness of fat in back and shoulders and more kidney fat, while those of lot 2 showed greater weight of blood and internal organs.

Eighteenth Report, page 25.—Lot 1 (wide ration) dressed a higher percentage than lot 2, but there is no definite indication of higher percentage of adipose tissue. Photographs seem to show greater development of loin muscles in lot 2.

Eighteenth Report, page 44.—Photographs of the loin cuts seem to indicate much greater proportion of fat to lean in lot 2 (wide ration), but computed per 1,000 pounds live weight the amounts of internal organs and internal fat do not differ widely.

Nineteenth Report, page 17.—After the first six weeks the peas (lot 1) were relished better and eaten more freely than the corn. The carcasses of lot 1 were flabby with thicker outside fat and somewhat more internal fat.

Twenty-first Report, page 25.—The pigs of lot 1 were stunted, and on slaughtering large numbers of worms were found in the intestines. There is no proof of difference in relative development of lean meat and fat.

The experiments reported by the Iowa station[a] include two trials of "wide" versus "narrow" rations. In both cases the "wide" lot gained somewhat more per day and per pound of dry matter in the feed. In the first trial the "wide" lot ate somewhat more dry matter than the other; in the second trial this particular is not stated. In neither case were the differences very marked. It seems safe, therefore, to compare simply the computed protein supply (digestible) in the two cases, using the figures in Farmers' Bulletin 22 (revised) as the basis.

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[a] Iowa Experiment Station, Bulletin 48, pp. 373–451.

Comparison of rations of high and low protein content fed to hogs.

	Second experiment.		Third experiment.	
	High protein.	Low protein.	High protein.	Low protein.
Animals .... number..	5	5	5	5
Length of experiment .... days..	153	153	163	163
Average age at beginning .... do....	54	51	52	52
Average weight at beginning .... pounds..	35.0	38.0	22.0	22.0
Average weight at middle of experiment .... do....	130.8	143.6	96.8	102.3
Digestible protein per day:				
Per head .... do....	.737	.431	.667	.462
Per 1,000 pounds weight .... do....	5.630	3.0	6.890	4.520
Average gain per day:				
Per head .... do....	1.26	1.38	.91	.98
Per 1,000 pounds weight .... do....	9.63	9.61	9.40	9.58

In the second experiment Swift & Co. valued the cuts as follows: High-protein lot, $6.40; low-protein lot, $7.13. The low-protein lot showed the largest percentage of dressed weight (79 as against 77.1), but was regarded as too fat, especially for the English market.

A representative animal of each lot was analyzed by the United States Department of Agriculture, the head, and the kidney and leaf lard not being included.

Calculated on dry matter, the composition of the carcasses was as follows:

Composition of carcasses of hogs fed on rations with high and low protein content.

Constituents.	High protein.	Low protein.
	Per cent.	*Per cent.*
Fat	81.38	81.52
Total protein	13.28	14.06
Ash	2.97	2.51
Lecithin	.16	.27
	97.79	98.36

The percentage of fat in the dry matter of the more important cuts was as follows:

Percentage of fat in the dry matter of different cuts of hog carcasses.

Cut.	High protein.	Low protein.
	Per cent.	*Per cent.*
Backs	92.43	92.41
Bellies	88.66	90.06
Hams	72.54	62.32
Shoulders	96.24	79.92
Spareribs	58.59	63.70
Tenderloins	34.11	40.98

Only in the case of the spareribs and tenderloins does the low-protein lot show any excess of fat, and even if we take the percentages calculated upon the fresh substance we add to this list only the hams. If the carcasses analyzed were representative, it would seem that the judgment of the market is based rather upon the distribution of the fat in the carcass than upon its total amount. In the third experiment the low-protein lot again dressed the highest percentage, but no definite statements appear as to the quality of the carcasses. It should be noted that in these experiments, as contrasted with those of the Wisconsin station, a considerable variety of feeds was given to each lot.

While the few experiments which have been cited are an entirely insufficient basis on which to formulate the protein requirements of pigs, it is evident that the very large amounts of protein consumed in some of these experiments were of no advantage so far as gain in live weight was concerned, and of questionable effect upon the make-up of the carcass. Making liberal allowance for the approximate nature of the data, it would seem that the following amounts of digestible protein per day per 1,000 pounds live weight were fairly sufficient for growing pigs:

	Pounds.
2 months old	3.00
4 months old	2.75
6 months old	2.50
8 months old	2.25

Further investigations and a systematic compilation of existing data are, however, greatly to be desired.

TOTAL FEED.

The same general principles which have been discussed in considering the total feed requirements of mature or nearly mature fattening animals may be safely assumed to apply also to younger animals, but their application is essentially modified by the fact that we can not greatly stimulate the growth of young animals by heavy feeding.

"Stockers."—As already noted, a large share of our meat supply is derived from animals reared until nearly mature and marketed as "stockers" to be finished by other parties, or, if older and of inferior quality, to swell the supply of canned meats and the like. Animals of this class are largely produced on cheap feed, grown on relatively cheap or rough land, generally under pasturage or range conditions. So long as large areas of cheap grazing land are available, as in the West and Southwest of the United States, it will be cheaper to ship the nearly mature animals destined for fattening to the feed than to ship the feed to the animals or to raise it in the locality, particularly at points distant from the great centers of consumption.

Under these conditions there is little call for anything in the nature of a feeding standard. The young animal runs with the dam until naturally weaned. The ordinary pasture or range plants are likely to be fairly rich in protein, and if the total supply is sufficient a normal rate of growth is assured. Whether the supply of feed shall be derived entirely from the natural growth, or whether this shall be supplemented by the growth of forage for winter feeding, is an economic question, to be decided according to local conditions.

Fat animals.—The production of "stockers" is not, of course, necessarily confined to the range; but at the same time, whenever any considerable expenditure is necessary for shelter and the growth of feeding crops, it becomes important to consider whether it may not be more profitable to finish the animals and market them in condition for the butcher. As has been shown, the rate of growth is largely a function of the individuality of the animal, and so far as the production of actual meat is concerned we are obliged to wait on the processes of nature. An attempt to force the animal prematurely by heavy feeding can result only in an overproduction of fat before the animal is of sufficient size to market, or before it has developed sufficient lean meat to yield a high-grade carcass. Fattening is relatively a more rapid process than growth in the sense that a sufficient amount of it to insure a high market quality of the meat may be accomplished in a much shorter time than is required for the growth of that meat.

The practical conclusion from these well-established facts is sufficiently obvious.

With any given type of animal, the age at which it will reach marketable form and size is fixed by the individuality of the animal, and so far as appears can be but slightly, if at all, hastened by the feeding. The earlier this point is reached the less, other things being equal, will be the feed cost of producing the animal; and on the other hand, the longer the animal is kept after that point is reached the less will be the profit to the owner.

In order that the animal shall be marketable for slaughter at that age, however, it must not only have produced the due amount of meat, but that meat must have the quality which is imparted by the fattening process. With this in view, we shall naturally aim to begin the feeding of fattening rations at such a point of time that when the actual growth of meat becomes so slow as to be no longer profitable the fattening process will also be completed. Too early a commencement of the fattening process will lead to waste in several ways. If the animals are pushed they become ripe before the possibilities of profitable growth are exhausted, and must either be marketed or else held at considerable expense until the growth can overtake the fattening. Moreover, it seems not improbable that too early fattening may actually be prejudicial to the production of lean meat, offering actual mechanical hindrances to its growth. If in the effort to avoid these drawbacks light feeding is resorted to, the period of time during which special care must be given to the feeding is unnecessarily prolonged. Beginning fattening too late unnecessarily extends the period during which the animal must be maintained and cared for without any compensating advantage, since the same gain of fat could have been secured earlier at no greater expense. Just when the fattening should begin will obviously depend upon the kind and individuality of the animal and upon the degree of fattening which the demands of the market and the cost of feed render desirable. The more rapid the rate of growth of the animal and the earlier it may be expected to reach maturity, the further back toward birth is the beginning of the fattening pushed, so that with small, quick-growing animals, like pigs, feeding and fattening may become almost synonymous.

It is not the present purpose of the writer to attempt to formulate numerically the total feed requirements of growing animals. Indeed he is inclined to question whether such standards, however accurate they may be made and however great their statistical value, can ever play any large part in practical feeding operations. Given a knowledge of the protein requirements, and of the means by which they may be satisfied, it may be questioned whether the observation of the skilled feeder, supplemented by occasional weighings, will not afford more satisfactory results than attempted adherence to a standard ration.

MANAGEMENT.

While the practical methods of management in stock feeding are outside the scope of a paper on feeding, nevertheless they have an important bearing upon the actual results obtained, and some discussion of the general principles involved may properly find a place here.

MUSCULAR EXERTION.

The well-known fact that muscular exertion is accomplished at the expense of the metabolism of tissue, and ultimately, therefore, at the expense of the feed, would seem at first thought to indicate that the activity of the meat-producing animal should be restricted as much as practicable. In the case of the growing animal, however, another very important element enters into the case, namely, the fact that moderate exercise tends to stimulate the growth of the muscular system, or, in other words, the production of lean meat. Since this is the essential object sought, a normal and reasonable amount of muscular activity on the part of the growing animal should be allowed and encouraged, even though the muscular exercise involves the consumption of more feed. Accordingly, young stock should be given the freedom of the pasture or range to as great an extent as practicable, while at the same time care should be taken to supply abundant feed containing a sufficient supply of protein, in order that sufficient material may be present to supply the demand for growth stimulated by the exercise.

In the case of breeding stock especially, a most important consideration is that of the health and stamina of the animal, which can hardly fail to suffer through overconfinement. The above principles apply in a general way to all classes of stock. In particular, hogs should be given an opportunity for more movement and exercise than is frequently allowed.

In the case of animals which have reached the fattening stage, on the other hand, there is comparatively little growth of protein tissue, while we only need to maintain sufficient health to insure a normal appetite and assimilation of food. In proportion, then, as this stage is reached we should endeavor to reduce the amount of exercise taken and to keep the fattening animal as quiet as possible. To this end comfortable quarters should be provided, with plentiful bedding, and the animals should be kept as undisturbed as possible, so that they may "eat and lie down." Results of experiments at the Pennsylvania station have shown an increase of 30 to 40 per cent in the metabolism of the same steer standing as compared with lying down. This is particularly important in the case of the sheep on account of its timid nature. For similar reasons it is desirable to have the water supply of fattening animals close at hand.

WATER SUPPLY.

It should never be forgotten that rapid production, involving the utilization of relatively large amounts of feed, requires the consumption of a corresponding amount of water for the physiological purposes of the animal. For this reason, as well as for the one mentioned above, it is desirable that stock should have ready access to water, if possible, at all times. Furthermore, the water supplied should not be too cold to be consumed freely by the animals.

SHELTER.

From the physiological point of view, considerable emphasis has been laid in the past upon the economic importance of providing fairly warm quarters for live stock in order to avoid a wasteful oxidation of the food for simple heat production. At the same time, however, vast numbers of cattle were being successfully fattened in sheds and open feed lots, and more recently the results both of physiological investigation and of practical experiments have led to considerable modification of the views formerly held. In the aggregate a considerable amount of experimental work is on record, of which the following is a condensed summary:

EXPERIMENTAL RESULTS.

Cattle.—Patrick and Smith,[a] as part of an experiment on the winter fattening of steers, compared two 3-year-old steers fed in a yard provided with an open shed with two others fed in the barn. Both pairs gave similar gains in a first period of twenty-four days on approximately like rations of corn-and-cob meal and corn fodder in the barn. Steers Nos. 5 and 7 were then transferred to the yard and the feed was changed to shelled corn and corn fodder, which was continued for thirty-seven days, results for the last thirty-one days (February 1–March 3) being reported. The dry matter eaten per pound of gain in live weight by the two lots and also by a comparison lot in the barn on unchanged feed was as follows:

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[a] Iowa Experiment Station, Bulletin 6, p. 205.

Comparison of results of steer feeding with and without shelter.

Steers.	Period I.		Period II.	
	Feed.	Dry matter per pound of gain.	Feed.	Dry matter per pound of gain.
		Pounds.		*Pounds.*
Nos. 4 and 8 (comparison lot).	Corn-and-cob meal and corn fodder, in barn.	6.86	Corn-and-cob meal and corn fodder, in barn.	15.72
Nos. 6 and 9	do	7.44	Shelled corn and corn fodder, in barn.	11.84
Nos. 5 and 7	do	6.82	Shelled corn and corn fodder, in yard.	13.61

The lot fed in the yard ate much more corn and less fodder than the comparison lot in the barn. On their face the results appear to favor the indoor feeding, but the differences are not large, and in view of the small number of animals and of the short period following a change of feed their value may be questioned. The winter is said to have been an unusually mild one. The authors note (loc. cit., p. 237) that sudden changes of temperature affected the gains unfavorably both in the shed and in the barn.

Gulley[a] obtained much inferior results with six Texas range steers fed in an open lot as compared with six others dehorned and fed in an open shed, but it is not clear how far the greater quietness caused by dehorning affected the results.

Georgeson[b] fed two lots of five three-year-old grade Shorthorn steers on ear corn, corn stover, and prairie hay for six months, one lot being tied in the barn and the other loose in a yard provided with an open shed. The difference in mean weekly temperature between barn and shed ranged from 2.7° F. in May to 35.5° in January, but was not less than 11.3° during the winter months. The lot in the yard ate more grain and hay than the one in the barn. The weather is stated to have been generally dry and clear and favorable to outdoor feeding. The lowest weekly mean reported is 6.1° F. in January. The feed consumption per pound of gain was as follows:

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[a] Texas Experiment Station, Bulletin 6.

[b] Kansas Experiment Station, Bulletin 34.

Consumption of feed per pound of gain by steers confined in barn and loose in yard.

Place.	Ear corn.	Corn stover.	Prairie hay.
	Pounds.	*Pounds.*	*Pounds.*
In barn	14.17	2.93	1.79
In yard	15.57	2.90	2.15

Sanborn [a] fed two lots of steers, one in the barn and one in the open air, from December 27 to April 20, reversing the lots on February 12. The grain ration was the same in each case, but the cattle out of doors ate their coarse fodder more completely.

Results of steer feeding in barn and in open air at the Missouri Experiment Station.

Place.	Feed consumed.		Gain.
	Grain.	Coarse fodder and silage.	
	Pounds.	*Pounds.*	*Pounds.*
In barn	2,736	4,202	381
In open air	2,736	5,209	374

The average temperature during February was 48° F. in the barn and 26° F. in the open air, the weather being dry.

Sanborn [b] in 1890-91 found that three steers fed in a yard protected from winds, but with no shed, ate more coarse feed and made greater gains, both absolutely and per unit of feed, than three comparison lots fed in the barn. The data cover the time from January 15 to April 1, and the weather is stated to have been dry and quiet with moderate temperature, the lowest being 12° F. and the average 23.4° F. It is thought that the greater opportunity for exercise in the yard accounted in part for the greater feed consumption and consequent greater gain. In the following year [c] the exposed lot on limited feed gained as much as the lot tied in the barn, but less than one in a box stall. When fed ad libitum, however, the exposed lot made a notably greater gain than either lot in the barn with no greater relative consumption of feed. The winter was "an average one in temperature with unusual snowfall and frequent spring rains." In the next year [d] a lot in an open yard and one in an open shed each ate more feed than one in a box stall in the barn when both were fed all they would eat. The total gains and the gains per unit of feed were greater in the box stall and least in the shed. If, however, the gains for the preliminary period be included, but little difference appears in the gain per unit of feed. The winter was an average one. The average temperature of the barn was 43.1° F. and that of the yard and shed 28.1° F.

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[a] Synopsis of experiment at the Missouri Experiment Station, p. 1.

[b] Utah Experiment Station, Bulletin 11.

[c] Utah Experiment Station, Report for 1892, pp. 21-25.

[d] Utah Experiment Station, Bulletin 23.

Thorne and Hickman[a] fed two 3-year-old steers in the barn and a similar lot in an open shed in 1894 and 1895. The average results for the two lots are reported as follows:

Results of steer feeding in barn and in open shed at the Ohio Experiment Station.

Place.	Daily gain per head.	Dry matter of feed per pound of gain.
	Pounds.	*Pounds.*
In barn	1.99	10.20
In shed	1.93	10.53

Shaw[b] fed seven steers, past 2 years old, tied in the barn, as compared with the same number in an inclosed shed open on a yard, for one hundred and forty days, with the following average results per day and head:

Results of steer feeding in barn and in shed at the Minnesota Experiment Station.

Place.	Feed consumed.		Gain.	Total feed per pound of gain.
	Hay.	Grain.		
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
In barn	11.31	13.36	1.74	14.18
In shed	10.74	16.21	2.26	11.92

Waters[c] reports four similar trials with fattening steers, each covering over one hundred days with four or five steers in each lot. One lot in each case was fed in a moderately tight barn but turned out for eight hours on pleasant days, one lot was fed in an open shed, and a third lot in an open lot. The daily results per head were as follows:

Average daily results of feeding steers with different degrees of protection at the Missouri Experiment Station.

Year and place.	Feed consumed.		Daily gain.	Total feed per pound of gain.
	Hay.	Corn.		
1897-98.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
In barn	8.57	18.35	1.47	18.31
In shed	9.52	19.89	1.72	17.10
1898-99.				
In barn	10.09	19.57	1.85	16.03
In shed	8.07	21.53	2.30	12.87
In open lot	10.09	19.57	2.29	12.95
1899-1900.				
In barn	7.00	19.00	1.67	15.93
In shed	8.00	19.46	1.69	16.25
In open lot	7.00	18.62	1.78	14.39
1900-1901.				
In barn	5.20	19.96	1.83	13.75
In shed	6.29	21.76	1.97	14.24
In open lot	8.81	24.26	2.09	15.82

Waters also reports that, in response to a letter of inquiry, out of 663 feeders of beef cattle in Missouri, Illinois, Iowa, and Nebraska,

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[a] Ohio Experiment Station, Bulletin 60, p. 24.

[b] Minnesota Experiment Station, Bulletin 76, p. 250.

[c] Monthly Bulletin, Missouri Board of Agriculture, September, 1901, p. 23.

546, or over 83 per cent, preferred to feed in an open shed or lot rather than in the barn, and that the "barn" described by many of the remaining 117 was little more than a large open shed.

Waters calls attention to the fact that the above results were all upon cattle on full feed and that they do not apply to young thin animals or breeding cattle, and states that four years' experiments on yearlings have given decisive results in favor of barn feeding.

Mairs[a] compared feeding in a warm barn with that in an open shed for four consecutive winters with lots of 12 steers each, the feeding covering from eighty-four to one hundred and twenty-six days. The total feed (grain and coarse fodder) consumed per pound of gain in the four experiments was:

Total feed consumed per pound of gain by steers at the Pennsylvania Experiment Station.

Year.	In barn.	In shed.
	Pounds.	*Pounds.*
1902-3	13.40	14.60
1903-4	13.81	15.32
1904-5	18.67	18.42
1905-6	16.07	15.80

These experiments differ from some of those noted above in the fact that the grain ration eaten by the two lots was nearly the same and that slightly less coarse fodder was eaten in the shed than in the barn. It was practically a test of equal rations under the two conditions. Mairs was unable to trace any connection between the temperature record and the rate of gain, and is inclined to ascribe the poorer results in the shed for the first two years to uncomfortable quarters.

While the foregoing results are more or less divergent, it is worthy of note that the experiments covering a full fattening period, with one exception (Georgeson), show fully as good results for the exposed as for the barn-fed animals. It seems clear at least that the value of shelter for fattening cattle has been exaggerated.

Sheep.—Sanborn[b] fed one lot of long-wooled sheep in the barn and a comparison lot in the open air from December 4 to May 10, with the following results:

Results in sheep feeding in barn and in open air at the Utah Experiment Station.

Items.	In barn.	In open air.
Preliminary, fourteen days:	*Pounds.*	*Pounds.*
Gain	18	19
Feed eaten	143	168
Feed per pound of gain	7.94	8.84
First period, thirty-five days:		
Gain	12	19
Feed eaten	265	278
Feed per pound of gain	22.08	14.63
Second period, one hundred and five days:		
Gain for first sixty-two days	45	36
Total gain	26	0

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[a] Pennsylvania Experiment Station, Bulletins 64, 68, 74, and 83.

[b] Utah Experiment Station, Report for 1892, p. 25.

During the last month both lots lost weight, but the feed consumption is given for the whole period only. This loss is ascribed to the moister storms of the late winter and early spring.

The same author reports briefly[a] the results of a second comparison with lambs, covering four weeks, in which the greater gain was made by the lot in the barn at an average temperature of 43° F., compared with a lot in an open shed at 28° F. The author believes that wet weather affects sheep more injuriously than cattle on account of the long time required for the wool to dry.

In an experiment on fattening lambs Shaw[b] fed similar rations to three lots of eight 6-months-old lambs each, one in an open yard, one in a shed open to a yard, and one in the barn. The following results are reported per day and head:

Experiments in sheep feeding at the Minnesota Experiment Station.

Lot.	Total feed eaten.	Gain.	Feed per pound of gain.	Cost per pound of gain.
	Pounds.	*Pounds.*	*Pounds.*	*Cents.*
Lot 1, yard	2.96	0.280	10.58	5.36
Lot 2, shed	3.18	.321	9.96	4.71
Lot 3, barn	3.09	.284	10.87	5.41

F. B. Mumford[c] fed two lots of 10 lambs each, averaging about 85 pounds live weight, one being confined in a well-ventilated (and apparently cold) barn, while the other was fed in similar quarters but with the run of an open yard, where they were frequently exposed to rain and snow. The results for thirteen weeks were:

Experiments in sheep feeding at the Michigan Experiment Station.

Lot.	Total feed eaten.			Gain.	Dry matter per pound of gain.
	Grain.	Hay.	Dry matter.		
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Lot 1, outdoor	1,196	1,087	1,978	205	9.65
Lot 2, indoor	1,164	1,173	2,019	230	8.77

Middleton[d] compared feeding sheep in an open shed and out of doors on similar rations. The average daily gain per head was: In the shed, 0.168 pound; out of doors, 0.189 pound.

On the whole such scanty data as are available seem to indicate that sheep do not stand exposure, especially to rain and snow, as well as cattle, and that shelter from storms is a not unimportant factor in mutton production.

Swine.—But few experiments with swine bearing on the subject under discussion are on record.

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[a] Utah Experiment Station, Bulletin 23, p. 7.

[b] Minnesota Experiment Station, Bulletin 44, p. 280.

[c] Michigan Experiment Station, Bulletin 128.

[b] Experiment Station Record, vol. 15, p. 897.

Shelton[a] fed five yearling swine in a warm barn in comparison with five similar animals in an open yard without shelter, the feed being shelled corn in both cases. The results for the ten weeks of the experiment were:

Results of pig feeding, with and without shelter.

Items.	Sheltered.	Exposed.
Average temperature .... °F..	29.9	15.8
Total feed .... pounds..	2,878	2,844
Total gain .... do....	604	[b] 489
Feed per pound of gain .... do....	4.76	[b] 5.82

Two of the animals in the exposed lot made practically the same gain as the average of the sheltered lot, although one of the two also ate decidedly more feed. The following comparison of the periods of highest and lowest temperatures is also of interest:

Comparison of the effects of high and low temperature during hog-feeding experiments.

Items.	Highest temperature.		Lowest temperature.	
	Sheltered.	Exposed.	Sheltered.	Exposed.
Average temperature .... °F..	37.3	26.3	22.3	2.5
Total feed .... pounds..	1,184	1,245	1,087	997
Total gain .... do....	301	[c] 260	190	88
Feed per pound of gain .... do....	3.93	[c] 4.79	5.71	11.43

Compared in this way, the effect of the shelter during the severe weather is very marked. The gain of the exposed animals during these weeks were very irregular and frequently negative.

Sanborn[d] fed two lots of shoats, one in an open shed and one in the basement of a warm barn, reversing the lots at the end of forty-two days and continuing the experiment for seventy days more. The totals per head for the entire experiment were:

Results of pig feeding in barn and in open shed at the Missouri Experiment Station.

Place.	Feed.		Gain.
	Corn meal.	Skim milk.	
	Pounds.	*Pounds.*	*Pounds.*
In barn	463.5	18	83.9
In shed	463.5	18	74.8

The same author[e] obtained the following results in a later experiment of the same sort, covering one hundred and thirty-six days from December 9.

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[a] Kansas State Agricultural College, Report of Professor of Agriculture, 1883, p. 1.

[b] Figures differ from those reported by the author.

[c] Figures differ from those computed by the author.

[d] Synopsis of experiments at the Missouri Experiment Station, p. 4.

[e] Utah Experiment Station, Bulletin 23, p. 4.

Results of pig feeding at Utah Experiment Station.

Place.	Grain consumed.	Total gain.	Feed per pound of gain.
	Pounds.	*Pounds.*	*Pounds.*
In barn	1,432	237	6.04
In shed	1,702	254	6.70

Friis[a] notes that the alleged effect of maize and of sunflower cake in producing soft pork is more marked in cold weather.

GENERAL PRINCIPLES REGARDING SHELTER.

The foregoing results, while indicating that the requirements of meat-producing animals for shelter may have been overestimated, nevertheless render it clear that the question is one of adaptation to conditions and that no invariable rule can be laid down. It may be profitable, therefore, to turn to a consideration of the scientific principles involved.

Temperature.—As the writer[b] has pointed out in discussing the energy relations of the feed and the animal, there is a certain approximate temperature, called the critical temperature, at which the minimum outflow of heat just balances the necessary heat production as a result of the internal work, and below which more or less oxidation of tissue is required to maintain the normal temperature of the body. Furthermore, it has been shown that the digestion and assimilation of the feed and its conversion into tissue result in the evolution of relatively large amounts of heat, especially in the ruminants, and that the effect of this internal production of heat is virtually to lower the critical temperature as compared with that of the fasting animal. In other words, there is for each animal and for each ration a certain temperature above which the heat produced becomes in part an excretum, to be gotten rid of by radiation and evaporation.

It appears likely that a certain excess of heat production over that absolutely required to maintain the body temperature is advantageous, both as promoting the comfort of the animal and especially as affording a margin in case of temporary fluctuations of temperature. On the other hand, both our own personal sensations and the observations of practical stock feeders show that an unnecessarily high temperature is debilitating, affecting both appetite and general health. In practice, then, we should endeavor to keep the thermal surroundings of the animal within the range above indicated—somewhat above the critical point but not so much so as to affect appetite and thrift. It is evident that the limits of this range may vary widely with the kind of animal and with the character of the ration.

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[a] Experiment Station Record, vol. 11, p. 70.

[b] Principles of Animal Nutrition, pp. 353–359 and 432–438.

Amount and character of ration.—The influence of this factor upon the requirements for shelter is clearly indicated by what has already been said. The heavier the ration, other things being equal, the more heat will be evolved during its digestion and conversion into tissue, while with equal amounts of feed those materials which require the greatest expenditure of energy for digestion and assimilation will be the most abundant source of heat. Since, however, these are in general the bulky coarse fodders, the amount of them which can be consumed is limited and the heavier grain rations are practically those which supply the animal with the greatest surplus of heat. Mature animals on full feed thus have at their disposal a large amount of surplus heat and naturally can thrive under conditions of exposure which might be seriously detrimental to young, growing animals on relatively light rations. Thus one of Kellner's experiments (Ox E, Period III) gave the following results:

Fuel value of ration	calories	26, 660
Energy stored as gain	do	5, 920
Energy evolved as heat	do	20, 740
Computed maintenance requirement	do	15, 060
Excess of heat	do	5, 680
Excess over maintenance	per cent	37. 7

Age and weight of animals.—The internal work of like animals of different sizes, under like conditions, appears to be approximately proportional to their body surface, and there is even good ground for believing that this law applies to a large extent to animals of even the most diverse species and size. Since the action of external temperature is also approximately proportional to the surface, we should expect that the size of the animal would not be an important factor. In fact, however, the other conditions are rarely alike. The young animal in particular is likely to be getting a relatively lighter ration than the animal which is being pushed for the butcher, and thus to have less surplus heat at its disposal. Furthermore, while there appear to be no measurements on record of the relative surfaces of young and of mature animals, common observation would seem to indicate that it is relatively greater in the young animal. Finally, the indefinable factor of "hardiness" would seem to be in favor of the older animal.

Humidity.—The relative humidity of the air is an important factor in the temperature relations of the animal. Moist air tends to increase the conductivity of the hair or wool and thus in effect to raise the critical temperature. Accordingly, we should anticipate that in a dry climate, like that of the Northwest, animals might be safely exposed to a greater degree of cold than in a damp climate, like the winter of the seaboard States.

Precipitation.—An important factor in the case is the amount of precipitation (rain or snow) to be expected during the feeding period. In cold weather the low temperature of the water which penetrates to the skin of animals is the cause of a loss of heat which may be regarded as practically an addition to that due to the cold air, the extent of both losses being affected by the thickness of the animal's coat. Far more important than this, however, is the expenditure of heat required to dry out the coat after it is wet, and this, as it would seem and as some of the experiments with sheep seem to indicate, would be greater with the heavier coated animal when it has once become thoroughly wet. Still greater, relatively, is the heat required to melt snow falling on the animal, or upon which it is compelled to lie.

These effects, it will be observed, are largely independent of the indications of the thermometer, and it is clear that the nature of the climate as regards humidity and precipitation is quite as important a factor as the temperature in its bearing on the question of shelter, and that in many localities a roof to shelter the animals from storms may be as efficient as a tight barn. One advantage of the roof, already mentioned incidentally, is that it provides the possibility of a dry bed, thus not only adding to the comfort of the stock but avoiding expenditure of energy in warming up or evaporating water or melting snow or ice.

Wind.—All are familiar with the greater severity of a windy day as compared with a still one of the same temperature. A large part of the protective value of the clothing of man or the coat of an animal resides in the air entangled between the fiber of the material. Wind tends to replace this air with fresh, cold air and thus greatly reduces the protective effect. A wind-break, therefore, may have a distinct economic value in stock feeding.

Temperature of drinking water.—In general, the same considerations adduced in discussing the influence of the temperature of the air apply to that of the drinking water. Under heavy feeding, especially, unless in very cold quarters, the animal has a surplus of heat which it can apply to warming its drink. If, then, the latter is at a temperature to be consumed freely there would seem to be no occasion for heating it further, except for one important consideration. The temperature of the air acts continuously and with approximate uniformity. That of the water, on the other hand, acts only at intervals, often only two or three times per day. If, now, the animal consumes within a short time a large amount of cold water, a correspondingly rapid expenditure of heat is required to warm this water to the body temperature, and this demand may for a time exceed the supply of surplus heat and cause an increased oxidation of tissue or food material for the sake of heat production only. Such a loss can never be made good at a later hour, since, once converted into heat, the energy has escaped from the grasp of the body. Other things being equal, then, it will clearly be desirable to have the water consumption approximate as nearly as possible a continuous consumption by having it constantly accessible, while if stock are watered only at intervals the temperature of the water may need to be rather higher than in the other case.

Insolation.—The effects of the weather are appreciably modified by the exposure of stock to direct sunlight. Aside from any direct effect of the light as such, a not inconsiderable amount of heat is imparted to the body by the sun's rays. During cold weather this is likely to be a distinct advantage, but during the hot months the reverse is true. Since the animal can not reduce its heat production below that required for its internal work and for the digestion and assimilation of its food, it may seriously tax its powers to dispose of the additional heat imparted by the direct sunlight. In this case shelter of some sort may be required for opposite reasons to those obtaining during the cold months. For similar reasons a supply of cool, fresh water, and exposure to the wind may be of great advantage in helping the animal to get rid of its surplus heat.

VENTILATION AND LIGHT.

Scarcely any data are available as to the influence of these two factors apart from their relations to heat production. There is no question, however, that proper ventilation and reasonably light quarters will tend to promote the welfare of the stock, both by rendering the conditions less favorable for the development and transmission of germ diseases and by a direct effect upon the health and resisting powers of the animals.

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